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OPTIMAL SITES FOR SEEDLINGS OF
TEN CONIFERS

by

© ANGUS JOHN MCLEOD

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Optimal sites for seedlings of ten conifers" submitted by Angus John McLeod in partial fulfilment of the requirements of the degree of Master of Science.

ABSTRACT

This study dealt with the effects of soil moisture, soil texture, and vegetative competition on survival and growth of ten coniferous species. Tree seedlings were planted in soil monoliths on a moisture gradient ranging from poorly to rapidly drained. Two sandy loam and two silty clay soil monoliths were used. Each monolith was split into five zones running perpendicular to the moisture gradient. Effects of vegetative competition were assessed on one sandy loam and one silty clay soil monolith.

The species studied were western redcedar (Thuja plicata Donn.), Douglas fir (Pseudotsuga menziesii (Mirb.) Franco var. menziesii), western hemlock (Tsuga heterophylla (Raf.) Sarg.), white spruce (Picea glauca (Moench) Voss), lodgepole pine (Pinus ponderosa, Doubl. var latifolia Engelm.), ponderosa pine (Pinus ponderosa Laws.), black spruce (Picea mariana (Mill.) B.S.P.), tamarack (Larix laricina (Du Roi) K. Koch), Siberian larch (Larix sibirica Ledeb.), and western larch (Larix occidentalis Nutt.) (Fowells, 1965).

Data were analyzed by analysis of variance augmented with multiple comparisons of interaction means. Survival, height growth, and diameter growth of each seedling were assessed. Total root length of seedlings growing without competition was also assessed. Results from the experiment indicate:

1. Non-vegetated silty clay soil yielded the best survival, height, and diameter growth when all species are considered together.

2. Overall site preferences for each species tested are:

a) tamarack and western redcedar; survival and height growth - an imperfectly drained, non-vegetated silty clay soil.

b) western and Siberian larch, white spruce, and Douglas fir; survival and height growth - an imperfectly or moderately-well-drained, non-vegetated silty clay soil.

c) lodgepole pine; survival and height growth - a non-vegetated sandy loam with no apparent soil moisture preference.

d) ponderosa pine; survival - a vegetated sandy loam, with no apparent soil moisture preference.
height growth - a non-vegetated silty clay soil with no apparent moisture preference.

e) black spruce; survival and height growth - a poorly or imperfectly drained, non-vegetated silty clay soil.

f) western hemlock; survival - an imperfectly or moderately-well drained, non-vegetated sandy loam soil.
height growth - an imperfectly or moderately-well drained, non-vegetated silty clay soil.

3. Establishment of Siberian and western larch was poor. Once established, however, growth was superior to all other species tested.

4. Relative flooding tolerance for flushed seedlings showed that tamarack, Siberian larch and black spruce are very intolerant to complete submersion for periods up to 10 days. Douglas-fir was intermediate in tolerance and white spruce and lodgepole pine were very tolerant.

ACKNOWLEDGEMENT

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I would like to express my gratification to Oliver and Duncan nurseries for providing the seedlings of five species used in the experiment. Thanks go to the Canadian Forestry Service, especially Dr. L. Carlson, for the use of their cold storage chamber for hardening off seedlings.

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Chapter 1

INTRODUCTION

To date western Canada's forest managers have, mainly for economic reasons, maintained the practice of re-establishing the same tree species on harvested areas as that removed without considering the ecological niche requirements of the species used. Another reason for this approach is that managers know native cover is adapted to the site. Whether a foreign or unknown species is adapted to the same site is not always certain.

Uniform reforestration treatments are normally applied to entire cut blocks for economic reasons. This minimizes initial costs of regeneration operations but may lead to later re-treatment costs for fail areas because even small cut blocks may vary in site potential. The situation where the entire area of a clearcut can be considered to have no variation in physical properties is rare. Poorly regenerated parts of cut blocks must then be replanted to obtain the proper stocking, thus commonly doubling the cost for reforestration.

As a result, not only should each site be treated specifically to create a suitable environment for seedlings, but the choice of species should also be varied by site in order to maximize forest yield.

Western Canada has five major Forest Regions; Boreal, Subalpine, Montane, Coast, and Columbia (Rowe, 1972) within which several important conifers grow. These species might be used more widely for reforestration than at present. The term Forest Regions denotes a major geographic belt or zone, characterized by broad uniformity both in physiognomy and in composition of dominant tree species.

Within these Forest Regions the given tree species exhibit

remarkable flexibility in site preferences. A given site type might be repeated in each of the Regions, but for reasons of species migration and isolation no one tree species occupies all sites optimally suited for it.

The purpose of this study was to examine preferences of tree species on two different soil types, on a moisture catena, and under competitive pressure to determine if generalized statements can be made about specific species/site preferences. If sites can be categorized within Forest Regions (Lacate, 1969), they may be able to be extrapolated from one Region to the next, thus lending great flexibility to the choice of species used in reforesting the five western Forest Regions.

Another purpose of this study was to evaluate relative species tolerance to flooding when seedlings are actively growing.

The species used in this experiment were selected because of their economic importance to western Canada (Rowe, 1972).

Three species were chosen to represent the Coast and Columbia Forest Regions: western redcedar (Thuja plicata Donn.), Douglas fir (Pseudotsuga menziesii (Mirb.) Franco var. menziesii) and western hemlock (Tsuga heterophylla (Raf.) Sarg.).

Four species were chosen to represent the Boreal Forest Region: white spruce (Picea glauca (Moench) Voss), lodgepole pine (Pinus contorta, Dougl. var latifolia Engelm.), black spruce (Picea mariana (Mill.) B.S.P.), and tamarack (Larix laricina (Du Roi) K. Koch).

The Montane and Subalpine Forest Regions were represented in the experiment by western larch (Larix occidentalis Nutt.), and ponderosa pine (Pinus ponderosa Laws.). Siberian larch (Larix sibirica Ledeb.), is not native to North America but was included as an exotic.

Chapter 2

LITERATURE REVIEW

2.1 Silvics of species being tested.

Table 1 contains a compilation, in point form, of known information about the responses of the species being considered to the various parameters indicated. Empty spaces within this matrix imply lacking information.

2.1.1 White spruce.

Root growth begins earlier and ends later than terminal or radial growth. In Manitoba root growth usually begins around April 27 and continues until October (Wheaton, 1958).

Competition is severe on mesic sites. Due to tree seedlings being adversely affected by competition, true site potential for tree growth may be significantly decreased on high competition sites compared to some sites without competition. Thus the possibility exists that less productive sites could produce greater indices due to the greater volume of root-accessible soil (Sims and Mueller-Dombois, 1968).

White spruce may produce elongated or monolayered root forms depending on the soil properties, and water table fluctuations and annual siltation characteristics of the particular alluvial site (Wagg, 1973).

The elongated taproot-form usually occurs on well-drained Luvisolic soils where growth of the taproot is not restricted by soil texture, structure and drainage (Wagg, 1973). The composition of the elongated taproot consists of primary roots. This is due to the occurrence of a thin L-F-H layer in which secondary roots do not develop readily.

Monolayered root-forms, with or without vestigal taproots, are found in imperfectly drained to poorly drained Luvisolic and Greysolic

TABLE 1. LITERATURE REVIEW.

Environmental Parameters considered in the experiment	Generalized Relationships	Siberian larch	Douglas Fir	Western larch	Western redcedar	Tamarack	Black spruce	White spruce	Lodgepole pine	Ponderosa pine	Western hemlock	References
Soil texture	Optimal soil texture			Gravelly or loamy or sandy soil		Heavy clays or coarse sands	Loams or sandy loam soils	Loam soils	Silty clay to clay loam soils.	Sandy loam, gravelly loam, clay loam, loamy soil, and gravel.	Organic soils.	(Fowells, 1965)
Soil tension	1, 6 and 15 atmospheres tension have no effect on height growth.		Over 20 atmospheres tension, transpiration drops to 17% of maximum.					Cessation of photosynthesis occurs at 9 atmospheres. Over 20 atmospheres tension, transpiration drops to 2 - 5 percent of maximum.		Over 20 atmosphere tension, transpiration drops to 2-5 percent of maximum.		(Glerum and Pierpoint, 1968) (Lopushinsky, 1969) (Zavitkovski and Ferrell, 1968)
Light intensities and shade ratings	Optimal light intensities.		Intermediate	Intolerant except in seedling stage where tolerant.	Very tolerant.	Very tolerant.	Tolerant	Tolerant - reaches maximum photosynthesis at 5,000 ft-c.	Intolerant - not light saturated at 12,000 ft-c.	Intolerant - not light saturated at 12,000 ft-c.	Very tolerant.	(Baker, 1949) (Brix, 1972) (Cochran, 1972) (Fowells, 1965) (Pearson, 1950)
Moisture drainage class and moisture regime	Optimal drainage.		Well drained under heavy rainfall.	Well drained.	Imperfectly drained under high rainfall.	Imperfectly drained.	Poorly drained.	Imperfectly drained - mesic condition.	Well drained.	Well drained.	Well drained under high rainfall.	(Fowells, 1965) (Rowe, 1955)
Competition	Vegetative competition monopolizes available light, space and soil moisture and may cause mechanical damage		Responds satisfactorily to release from competition up to 100 years old.	On mineral soil without competition growth is twice as fast for at least 15 years.	Growth is retarded in proportion to the density of the shade.	Very unsuccessful in competing with other vegetation.	Seedlings will develop under competition with as little as 10 percent of full light. Superior development occurs in the open.	70 percent or better vegetation canopy reduces height growth considerably.	Reduces growth considerably.	Reduces growth considerably. Denuded plots show eleven fold greater gain in dry weight than those grown with vegetative competition.	Survives a very long time and even reaches maturity under competition but responds well to release.	(Crossley, 1969) (Fowells, 1965) (Meyer, 1937) (Mullin, 1969) (Pearson, 1950) (Place, 1955) (Wagg, 1973)
Flooding	Effects of flooding on certain species are shown. Flooding implies seedling submersion.					A fluctuating water table causes mortality.		Factors resulting in mortality are: - scarification techniques causing ponding.	Tolerates high water table but does not grow: -radial swelling -shallow rooting	Tolerates high water tables but growth is very slow -radial swelling -shallow rooting		(Cochran, 1972) (Denyer and Riley, 1964) (Lees, 1964)

soils (Wagg, 1973). This form may develop from an aborted or degenerate taproot in the seedling, possibly because of a rock or gley layer, or from degeneration of the lower part of the root system in the presence of a fluctuating water table. The root system, depending on the mode of development, consists of either primary and secondary or all secondary roots (Wagg, 1973).

2.1.2 Black spruce.

One of the most important phenological characteristics of black spruce, enabling it to successfully occupy the cold wet environments of muskegs, is the relative lateness of inception of growth (Le Barron, 1948). In 1961 black spruce started to grow about June 1st in Alberta which was about two weeks later than other species (Horton and Lees, 1961). Studies in muskegs in northern Ontario showed balsam fir (Abies balsemea (L.) Mill.) was damaged by late frosts while black spruce was not.

On drained sites, increased growth occurred over longer periods of time. This suggests that these trees occupied the increased soil depth (Groenewoud, 1975).

Most black spruce stands originate after fire and most stands are therefore even-aged (Vincent, 1973).

Black spruce root growth increases with increasing soil aeration up to mesic conditions and as nutrient availability increases. As seedlings grow larger, more rooting depth is required to sustain good growth. Increasing depth to water is therefore required as seedlings grow larger. Downward penetration of roots is limited by low oxygen levels. One study showed that black spruce in muskegs merely tolerates excess moisture but does not prefer such wet habitats (Mueller-Dombois, 1963).

2.1.3 Lodgepole pine and ponderosa pine.

Lodgepole pine is able to grow better at lower night temperatures and is less nutrient demanding than ponderosa pine (Cochran, 1972). Lodgepole pine had a lower night time transpiration rate than ponderosa pine. This was due to complete stomatal closure at night. Higher water potentials of lodgepole and ponderosa pine, when compared to Sitka spruce (Picea sitchensis (Bong.) Can.) and Douglas-fir, were due to greater sensitivity of the stomata of the pines to leaf moisture stress (Lopushinsky, 1969).

Ponderosa pine is quite adaptive to a large range of environmental conditions. Root growth of ponderosa pine is uninhibited by grasses providing there is abundant moisture (Schubert, 1974).

The rooting habit of lodgepole pine shows considerable variation. The taproot is dominant during seedling and sapling development but gradually becomes less significant as trees mature and develop lateral roots. Maximum lateral development occurs before the tree reaches polewood size. Windthrow becomes a serious problem if root development is restricted by layers of coarse soil, impermeable layers, high water tables, or dense stand conditions (Pfister, 1975).

2.1.4 Western larch.

Western larch outgrows most of its associated tree species. Western larch is intolerant to shade and therefore grows poorly in mixed stands. Studies have shown that on mineral soil seedbeds, larch grows twice as rapidly without vegetative competition as it does under heavily vegetative competition during the first 15 years of life (Fowells, 1965).

2.1.5 Tamarack.

Tamarack seedlings need full sunlight and ample water for

optimum growth. When vegetative competition is absent, seedlings can grow 6 to 8 inches in height per year in early life. However, a study in Alberta showed that height growth could be reduced to two inches per year in cold muskegs (Beeftink, 1951).

Tamarack usually exhibits a shallow, compact root system on soils with a high watertable. Taproots are rarely formed even on well drained soils. Instead, platelike rooting occurs with few roots reaching below one or two feet (Bannan, 1940). In bogs, tamarack roots are usually stringy with no branches on the terminal six inches. As the moss layer deepens, new roots develop on the stem above the original root collar and growth of old roots nearly ceases (Beeftink, 1951).

2.1.6 Siberian larch.

The author has been unable to find relevant literature for Siberian larch in North America. Siberian larch is only native to Russia. Any stands presently growing on this continent have been planted by man.

2.1.7 Western hemlock, western redcedar, and Douglas-fir.

Douglas-fir seedlings need light shade for best establishment but full sunlight for best growth. More than 25 percent shade may be harmful for growth. Shoot and diameter growth in Douglas-fir seedlings usually continue for 3 to 4 months after bud-burst. Douglas-fir requires more light than western hemlock or western redcedar (Fowells, 1965).

Western hemlock, western redcedar, and Douglas-fir all form taproots during the seedling stage. A rapidly developing taproot enables the seedlings of these species to penetrate into deep, moist horizons thereby assisting the seedlings to survive dry conditions (Eis, 1974).

Chapter 3

METHODS AND PROCEDURES

3.1 Seed source.

The seeds used were obtained from various sources. The one-year-old western redcedar, Douglas-fir, and western hemlock were grown as bare root stock at the British Columbia Forest Service provincial tree nursery at Duncan, British Columbia. The rearing regime under which these species were grown necessitated chilling the seedlings to encourage dormancy because some of the seedlings upon arrival in Edmonton were still partly active. The seedlings, shipped by air, arrived in Edmonton on November 26, 1975. These seedlings were kept in a cold storage chamber at the Northern Forest Research Centre in Edmonton. The temperature was maintained at a constant 4.4°C and only 50 ft-c of light were supplied. The seedlings were kept in cold storage until January 15, 1976 at which time they were removed and placed in a greenhouse so that flushing would occur. Flushing was uniform and occurred within two weeks after the seedlings were placed in the greenhouse.

The two-year-old white spruce and lodgepole pine were grown in Spencer-Lemaire Rootrainers at the provincial tree nursery at Oliver near Edmonton, Alberta. These seedlings were placed in a greenhouse on January 14, 1976 and kept moist. Flushing was uniform and occurred within two weeks after they were placed in the greenhouse. Table 7, Appendix 1 contains the location and other pertinent stand information for each species.

3.2 Rearing schedule.

A rearing schedule was devised for western larch, Siberian larch, tamarack, black spruce, and ponderosa pine. Temperature was

maintained at 21.5°C (± 3.5°C), light intensities exceeded 1000 ft-c over an 18 hour photoperiod, and the seedlings were irrigated with a nutrient solution every week for the duration of the schedule.

The seeds of each species were treated with hydrogen peroxide to destroy any seed-borne fungi and then planted in Spencer-Lemaire Rootrainers. In addition, black spruce and tamarack seeds were soaked in water overnight prior to being sown. Similarly, the ponderosa pine seeds were kept moist before planting to encourage maximum germination.

The rearing schedule was implemented on October 20, 1975 and continued for four months until the seedlings were planted in the soil monoliths. The fertilizer (N-20, P-5, K-30) was applied at a rate of one tablespoon in five gallons of tap water, one gallon per four Spencer-Lemaire trays. The rearing schedule is outlined in full below (Lees, 1975).

Day	Week	
0	0	Sow seeds of all species, water and cover; check periodically and water when needed.
14	2	Emergence almost complete. Thin or fill-in as needed.
21	3	Irrigate with nutrient solution.
28	4	Water.
35	5	Apply nutrient irrigation, water as needed between applications
42-63	6-9	Irrigate with nutrient solution.
67	9.5	Irrigate with nutrient solution. (Seedlings larger and entering phase of rapid growth, so require more frequent irrigation).
70-81	10-11.5	Irrigate with nutrient solution.
84	12	Irrigate with nutrient solution. (Remove seedlings to cold frames or reduce temperatures to 10°C if they are intended for field planting.) In the case of the experiment the temperature was reduced.

88-109	12.5-15.5	Irrigate with nutrient solution.
112	16	Irrigate with nutrient solution. (Seedlings ready for field planting.)

Western larch and ponderosa pine achieved less than 60 percent germination. All other species achieved in excess of 85 percent germination. All species responded well to the rearing schedule. Only the vigorous seedlings were planted on the soil monoliths. Extra seedlings were available to replace seedlings that died on the slopes, thus each soil monolith had equal numbers of actively growing, established seedlings before the formal experiment was commenced.

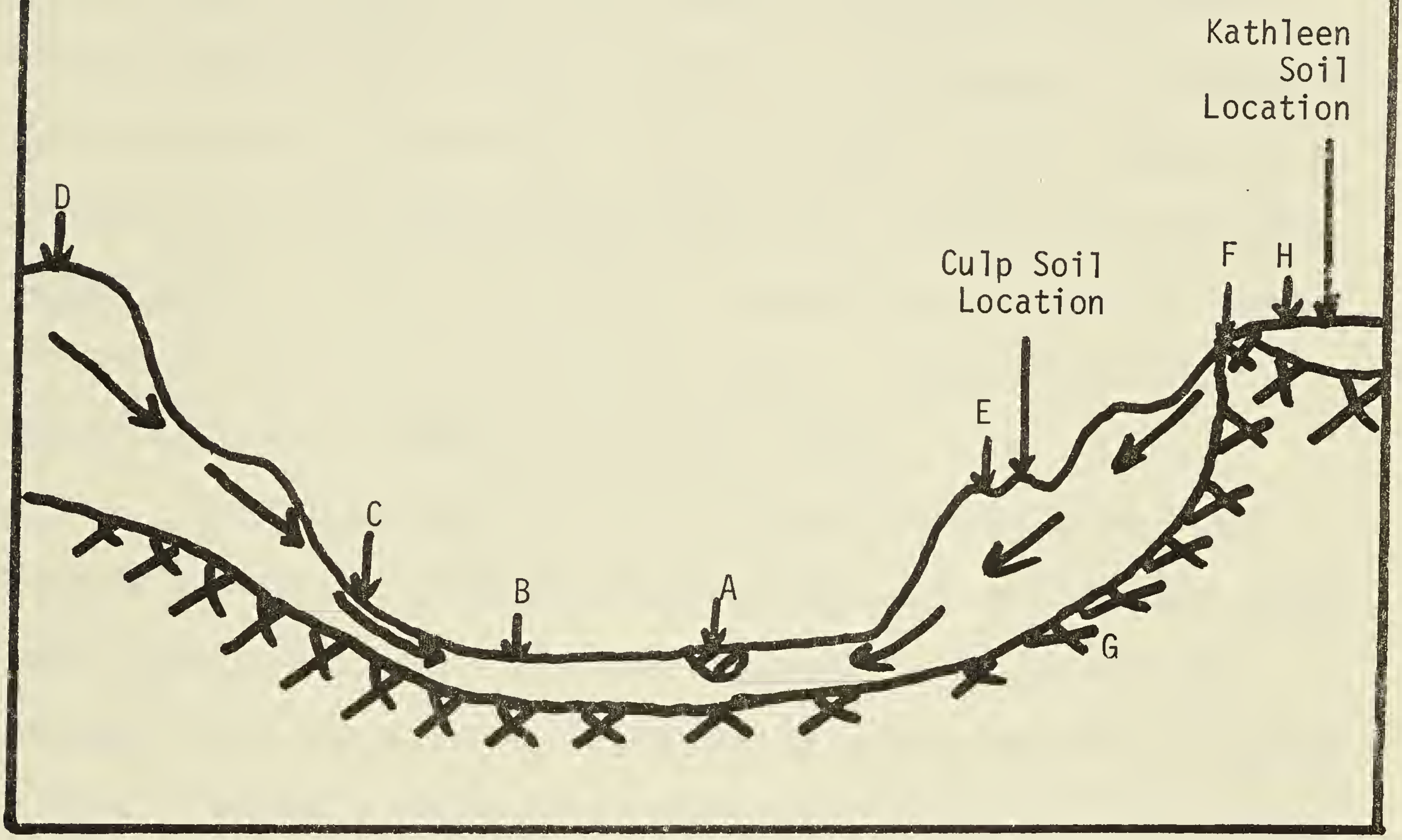
3.3 Soil description.

Two types of soil were used, which allowed a certain degree of generalization about the effect of soil texture on growth of coniferous seedlings. The two textural classes were sandy loam, and silty clay.

The Athabasca River Valley near Blue Ridge, Alberta was chosen as the location of the representative transect referred to in the introduction. Both textural classes of soil occurred along the transect. The sandy loam soil was located on the lower river terrace while the silty clay soil was located on the broad upper terrace. The sandy loam soil was collected in section 32, township 60, range 10, west of the 5th meridian and the silty clay soil in section 29, township 60, range 10, west of the 5th meridian. Figure 1 shows the transect of the Athabasca Valley.

The transect line across the Athabasca river valley cutting through the Boreal Forest Region (Figure 1) illustrates a repetitive landform pattern which contains infinite examples of variable moisture levels. This transect line represents what might be found in any of the five western Forest Regions and is used to illustrate the potential

Figure 1. Transect across the Athabasca Valley.



Code use for parent material and associated vegetation:

A. Athabasca river.

B. alluvial flood plain (black spruce, white spruce, tamarack)

C. colluvium (birch, alder)

D. glacial till (aspen, white spruce, lodgepole pine)

E. dune sand (pine dominates)

F. bedrock outcropping (lichens and grasses)

G. bedrock

H. lacustrine material

⟶ drainage pattern

applicability of the study results to this large western region of Canada.

The sandy loam soil belonged to the Culp soil series. Culp soils are well drained Orthic Gray Luvisols developed on moderately coarse textured alluvial-aeolion material. The topography associated with this soil series is undulating to gently sloping. Native vegetation is dominated by aspen (Populus tremuloides Michx.), balsam poplar (Populus balsamifera L.), shrubs, and grasses. Lodgepole pine and white spruce occasionally occur with the aspen and poplar. Culp soils are usually stone-free (Wynnyk, Lindsay, and Odynsky, 1969).

The silty clay soil used in the experiment was part of the Kathleen soil series. Kathleen soils are moderately well-drained, stone free, Orthic Gray Luvisols developed on moderately calcareous fine-textured lacustrine material. Topography is gently undulating to gently rolling. The native tree cover is mixed aspen, poplar and white spruce.

Figures 2 qnd 3 show natural vegetation on the Culp and Kathleen soil series respectively.

The A and B horizons were mixed in this experiment. A and B horizons are commonly mixed in the field after scarification. Native roots, contained within each soil sample, were not removed. The soils were transported separately by truck to Edmonton.

Chemical analysis of typical Culp and Kathleen soil series are shown in Table 2 (Wynnyk, Lindsay, and Odynsky, 1969). The Ae and Bt1 horizon, which represent the mixed soil horizons used in the experiment, show that the silty clay has over twice the cation exchange capacity of the sandy loam. The silty clay soil can therefore be considered more fertile and potentially more productive than the sandy loam soil for tree

Figure 2. Native vegetation growing on Kathleen soils.

Figure 3. Native vegetation growing on Culp soils.

TABLE 2: CHEMICAL ANALYSIS OF CULP AND KATHLEEN SOIL PROFILES

Horizon	(in.)	(cm.)	pH	N%	org. C%	C/N ratio	H%	Na%	K%	Ca%	Mg%	CEC me/ 100g	Ca/Na ratio
Culp sandy loam (alluvial)													
L-H	2	5	-	-	-	-	-	-	-	-	-	-	-
Ae	7	17.5	6.5	.03	.28	9	13	Tr.	4	70	13	4.7	70
Bt1	6	15	6.2	.04	.39	10	8	Tr.	3	70	19	10.0	70
Ae-Bt1	-	-	-	-	-	-	-	-	-	-	-	7.0	-
Bt2	6	15	6.7	.02	.41	20		Tr.	4	82	14	8.4	82
Ck1	10	25	8.1	-	-	-	-	-	-	-	-	4.9	-
Cca	5	12.5	8.1	-	-	-	-	-	-	-	-	-	-
Ck2	36	at 90	8.2	-	-	-	-	-	-	-	-	-	-
Kathleen silt loam (lacustrine)													
L-H	1	2.5	6.4	-	-	-	-	-	-	-	-	-	-
Ae	6	15	6.3	-	.68	-	17	2	4	65	12	8.9	34
AB	2	5	5.9	-	.85	-	11	1	2	38	48	19.6	38
Ae-AB	-	-	-	-	-	-	-	-	-	-	-	16.0	-
Bt	10	25	5.6	-	.53	-	9	1	2	68	20	30.2	68
BC	8	20	6.1	-	.62	-	6	1	2	75	16	28.2	75
Ck	at 27	at 67.5	7.5	-	.39	-	-	Tr.	1	90	9	16.5	90

growth. A detailed description of the soil profile of both the Culp and Kathleen soils is shown in Appendix 2.

3.4 Experimental hardware.

(a) Function:

The analysis of the effects of soil texture, soil moisture, and vegetative competition on seedling survival and growth was based on a controlled experiment where the effects of other environmental factors could be minimized.

The soil moisture catenas developed in the soil monoliths of this experiment are identical to those used by other authors for similar studies (Hewlett, 1961; Muller-Dombois, 1963; Cook, 1972).

(b) Description:

Four soil monoliths were constructed using rectangular boxes with level bottoms and sloping surfaces with a grade of 1:3 as shown in Figure 4. Inside each box a pipe 2 m long was attached to feed tapwater to the bottom to simulate ground water flow. The water table was controlled at the low end through a tap 15 cm above the bottom of the box. Illustrations of the rectangular boxes are shown in Figures 4 and 5.

The sides of the boxes were constructed of angle iron welded together into a skeleton upon which 3/4 in. plywood was bolted. Galvanized steel was installed for the flooring; this was then tarred to make it watertight. The tar did not dissolve into the water thus there was no adverse effect on seedling growth from the tar.

The boxes were first filled with roofing gravel to a depth of 10 cm. Then a 3 cm layer of coarse sand was added, and the boxes were topped up with either the Culp or Kathleen soils. Two of the four boxes were filled with Culp and two with Kathleen soil. The layers of coarse

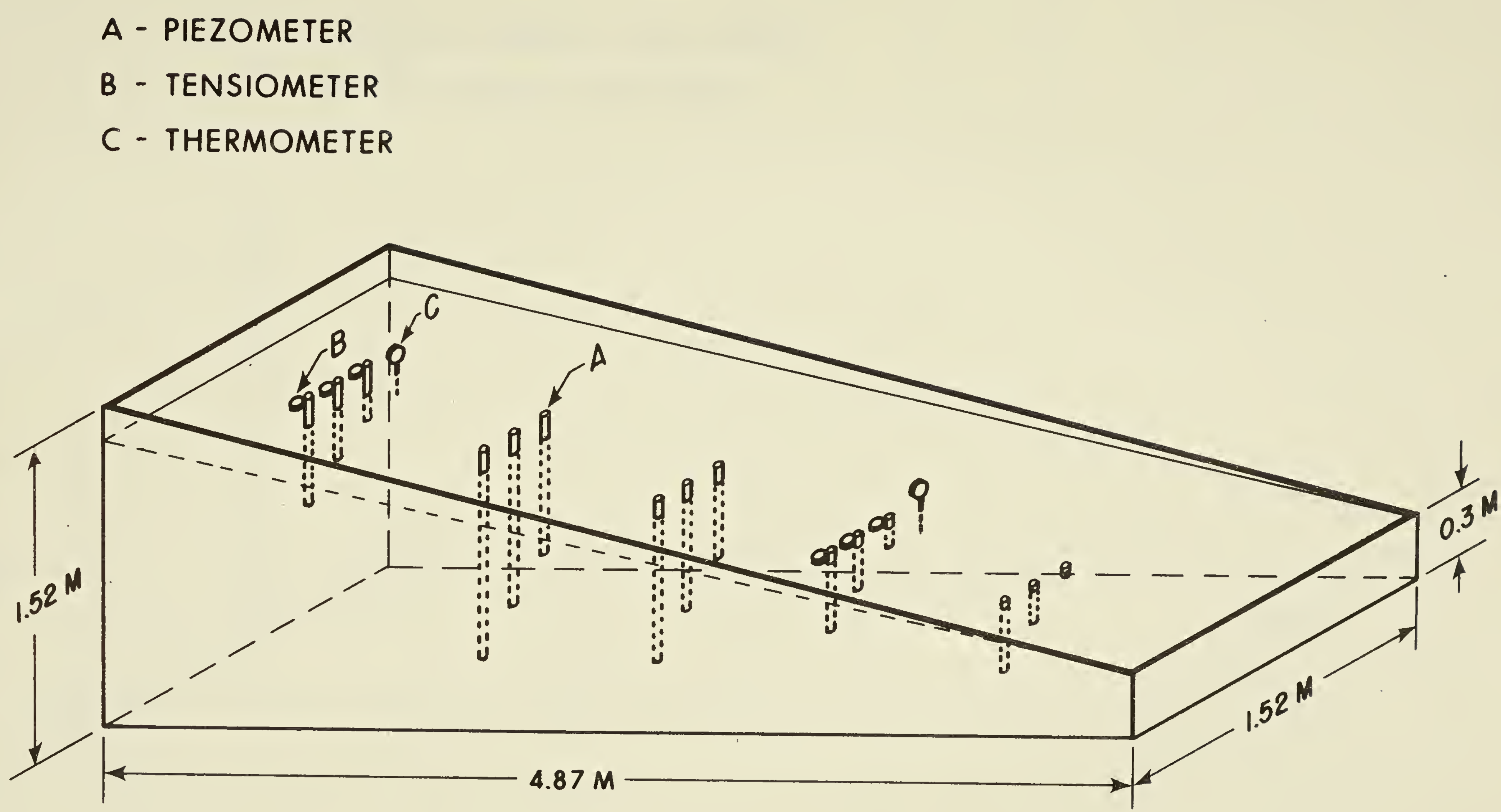

A - PIEZOMETER
B - TENSIOMETER
C - THERMOMETER
A
B
C
1.52 M
4.87 M
1.52 M
0.3 M

Figure 4.

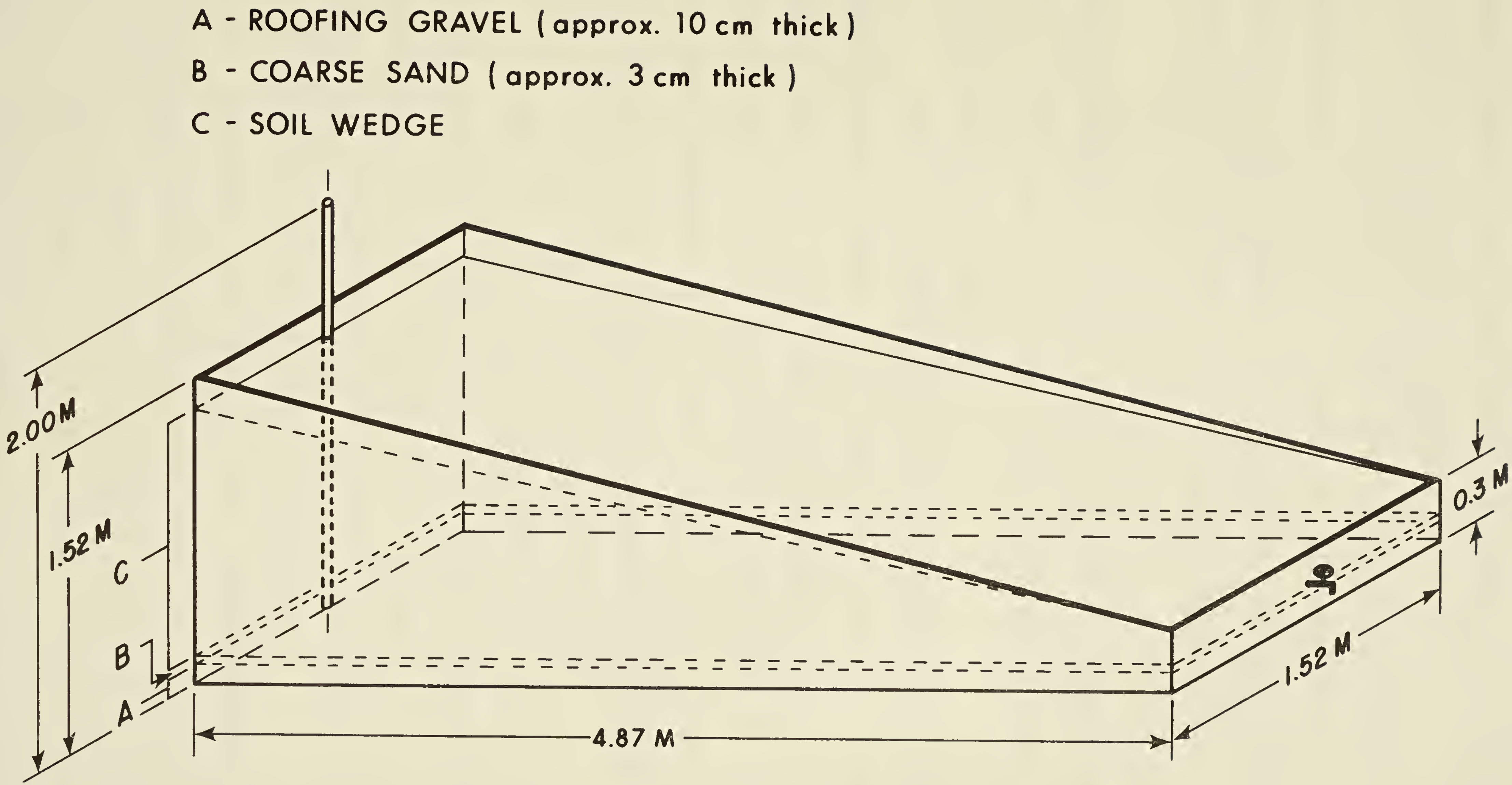

A - ROOFING GRAVEL (approx. 10 cm thick)
B - COARSE SAND (approx. 3 cm thick)
C - SOIL WEDGE
2.00 M
1.52 M
C
B
A
4.87 M
1.52 M
0.3 M

Figure 5.

sand and roofing gravel were installed so that the drainage of water through the box would not be impeded.

Soils were air dried before being placed in the boxes. While filling the boxes, care was taken to compact the soil as uniformly as possible. A bulk density of 1.1 gm/cm was obtained on both soils. The in-situ soil bulk density was 1.4 gm/cm for both soils.

The surface of each box was divided into five equal sections running perpendicular to the slope. The depth to water table ranged from 48 cm at the midpoint of zone 5 (top of the box) to 0 cm at the midpoint of zone 1 (bottom of the box).

Nests of piezometers, 1/2 in. diameter steel pipes used to measure the water table, were installed at one-third increments along the slope of each box. There were three piezometers per nest; one piezometer of each nest was set at the 15.24 cm base line from the bottom of the box, the second piezometer in each nest was set at the 30.48 cm base line from the bottom of the box, and the third piezometer in each nest was set at the 45.72 cm base line from the bottom of the box.

Sets of tensiometers, instruments that measure the moisture tension in the soil, were also installed; one in the middle of zone 2 and one set in the middle of zone 4 for each box. Three tensiometers were used per set; one was placed at a depth of 15.24 cm,one at 30.48 cm, and one at the 45.72 cm level from the soil surface.

The water table level was kept constant but water was allowed to flow through the box and out through the tap placed in the lower wall of each box. Figure 6 shows the drainage apparatus for the experiment.

The building was equipped with environmental controls which enabled a constant 25.5°C temperature to be maintained both day and night.

A lighting rack was constructed that would hold fluorescent and incandescent bulbs to provide the visible light spectrum at an intensity of 2000 ft-c of light at the soil surface. An automatic timer was installed to help maintain an 18 hour photoperiod. There was 0.61 m clearance between the soil surface and the light racks. Figure 7 shows the lighting system.

Figure 8 shows a representative sample of a nest of piezometers, a set of tensiometers, and a soil thermometer positioned on the bare slope of the silty clay soil box. Figure 9 shows tensiometers positioned on the vegetated, sandy loam soil box.

Artificial watering of the slope to simulate natural rainfall was carried out by means of an irrigation pipe which enabled a controlled flow of water to be applied along the slope. There was a need to determine a rainfall frequency that would represent the average condition in the Boreal Forest Region. The rainfall distribution from May 1 to September 1, 1972 for Hinton, Alberta area was arbitrarily chosen as the average for the Boreal Forest (Canada Atmospheric Environment Service, 1972).

Periodic fluctuations in the water table of about 2 cm were caused by diurnal fluctuations in line water pressure. The effects of this variability on experimental results were ignored. Difficulties were also encountered with runoff and erosion. The water added to simulate natural rainfall could not be added manually without causing erosion. A misting system might have worked but this problem was not envisaged before the experiment was well underway at which time it was too late to alter the method of application.

Two thermometers, which comprises a set, were placed at the

Figure 6. Drainage apparatus for each box.

Figure 7. Example of a lighting rack used in the experiment.

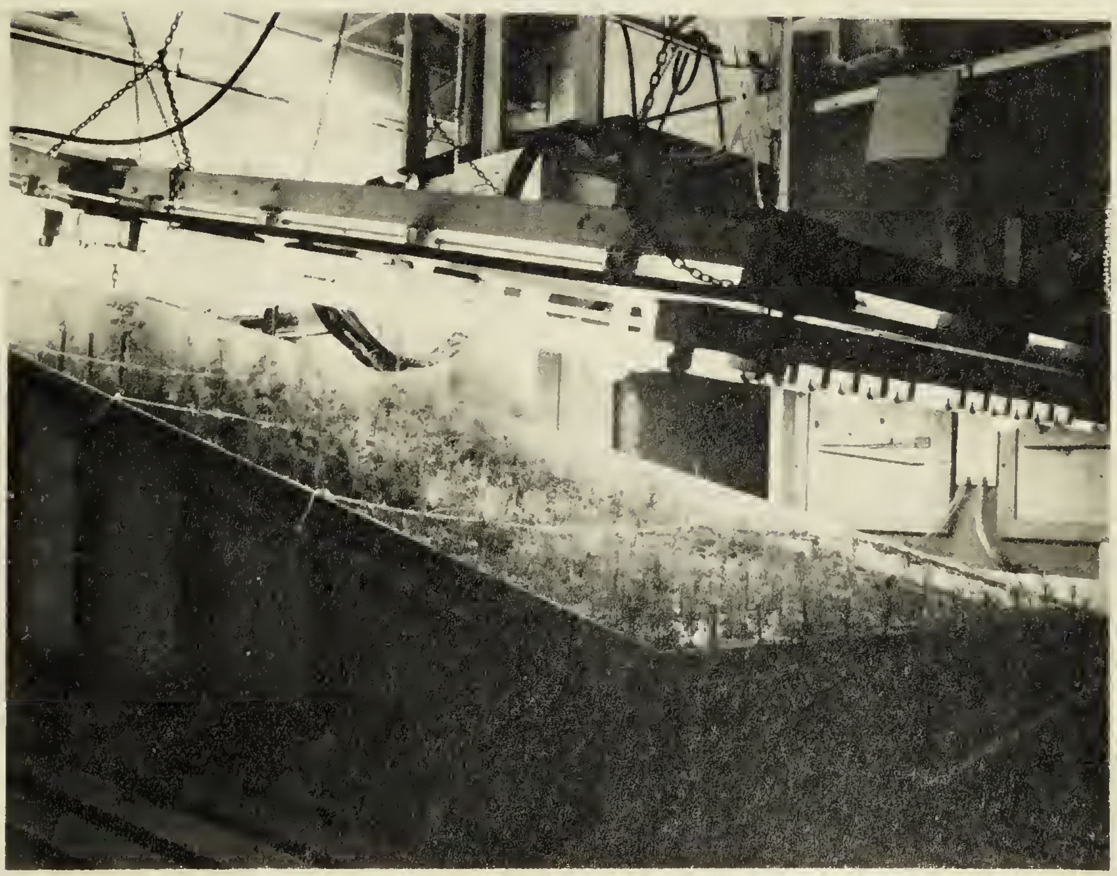


Figure 8. Example of tensiometers, piezometers and thermometers positioned on the slopes.

Figure 9. Tensiometer positioned on a vegetated slope.

15.24 cm depth from the soil surface; one in zone 2 and one in zone 4. One set of two thermometers was placed in the non-vegetated sandy loam soil box and the other set was placed in the non-vegetated silt clay soil box.

Average moisture level distribution, and water level fluctuations within the soils are shown in Appendix 6. Table 2 shows that the average depth to water table was greater in the sandy loam soil than in the silty clay soil. There was no apparent difference in the average wetted perimeter in the two soils.

Zone 5 was rapidly drained. Soil moisture content seldomly exceeded field capacity at any level within the rooting zone except immediately following simulated rainfall. This was true for both soil textures.

Zone 4 was well drained. Soil moisture was rarely greater than field capacity in the rooting zone (Figure 10),even after watering.

Zone 3 was moderately well-drained. Soil moisture exceeded field capacity following the addition of surface moisture for longer periods of time than in zones 4 or 5.

Zone 2 was imperfectly drained. Soil moisture in excess of field capacity remained in the lower part of the rooting depth where groundwater started to have an effect. Figure 11 shows that the soil moisture content was at field capacity at the 15.24 and 30.48 cm soil depths for both soils used. Only the upper 15.24 cm of soil had a water content below field capacity.

Zone 1 can be considered poorly drained. Soil moisture was in excess of field capacity throughout the rooting zone.

Stir pits under the floor enabled runoff and waste water from

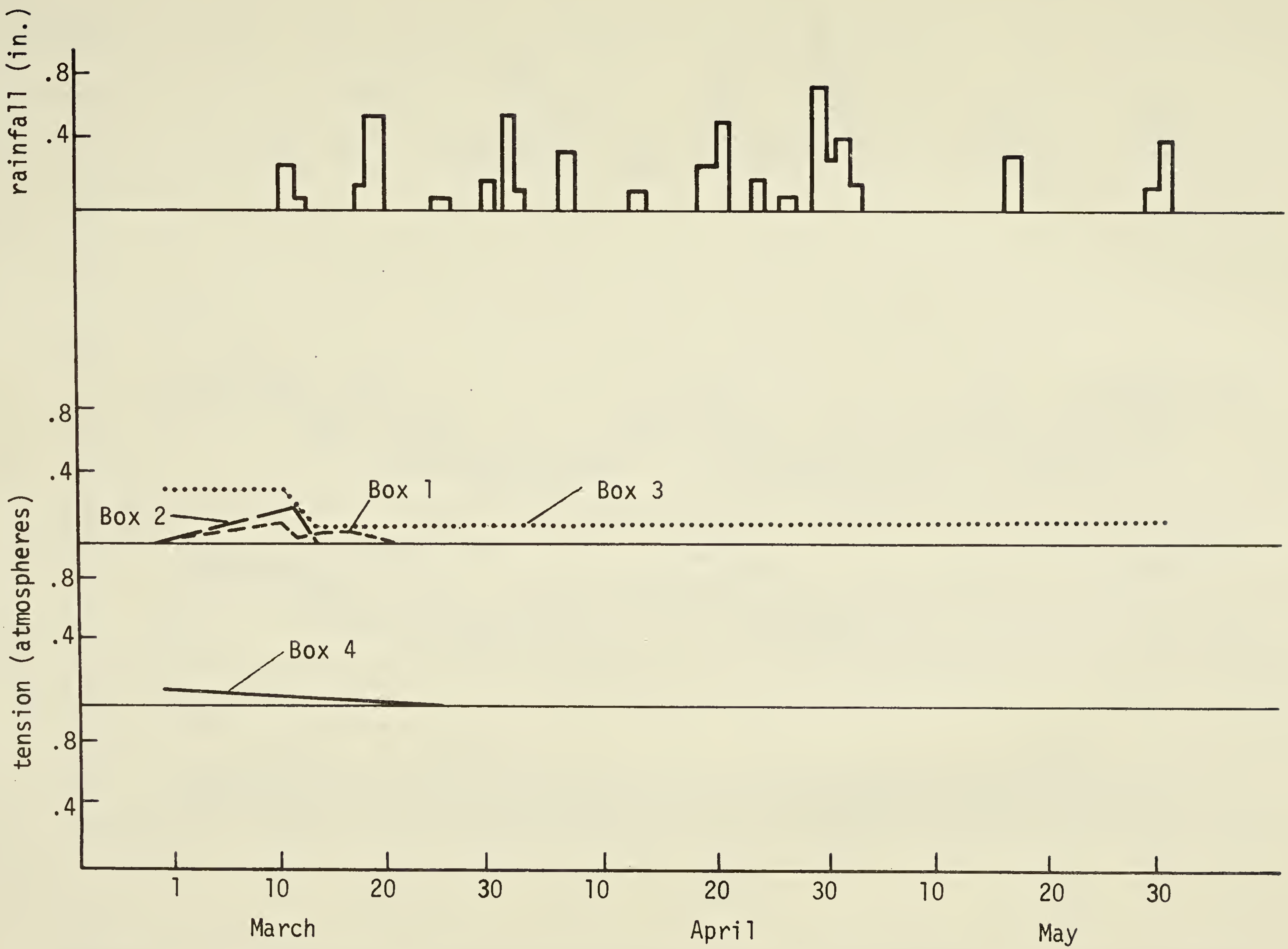


Figure 10. Soil moisture relationships in zone 4 for all treatments at varying soil depths.

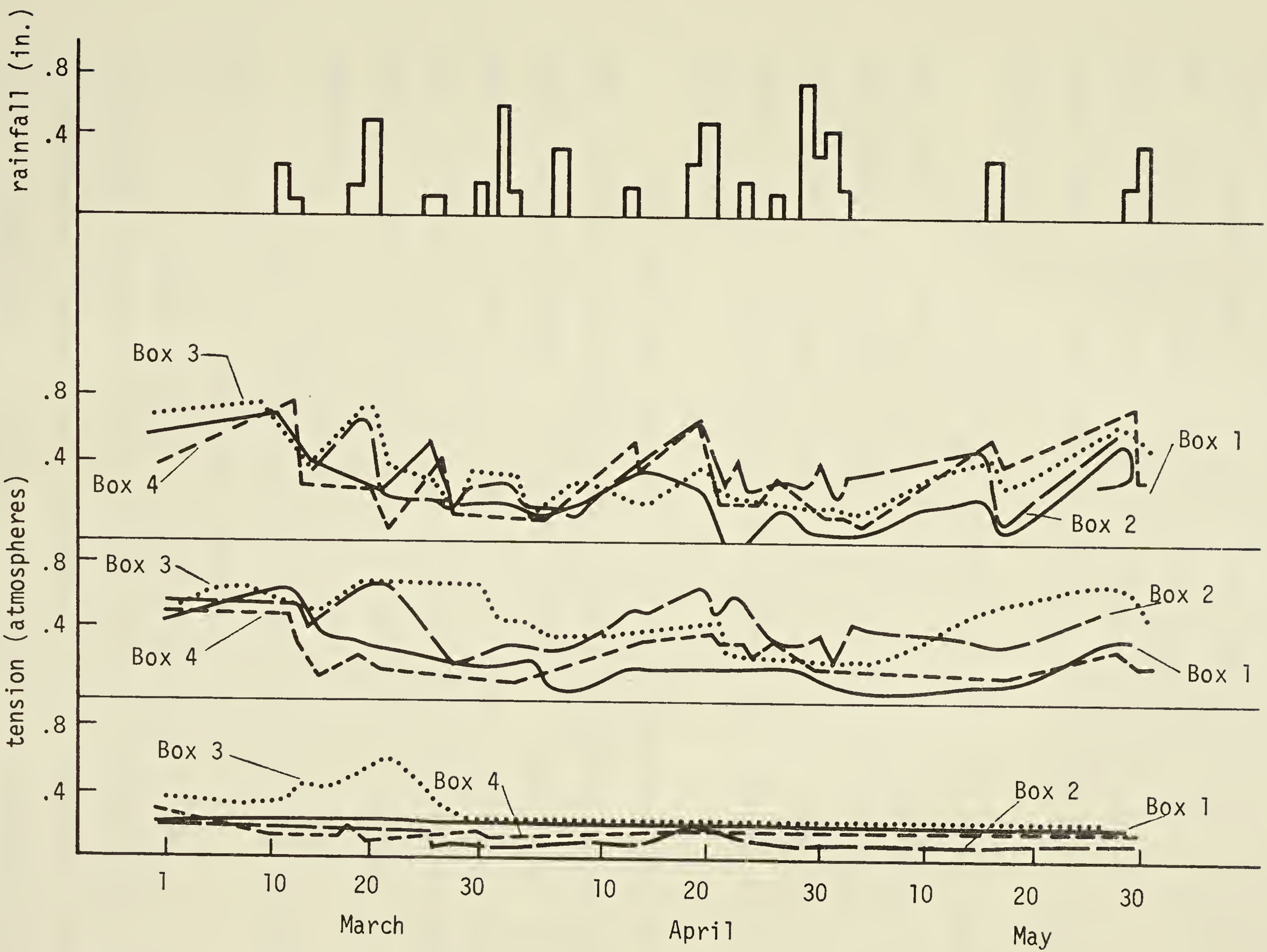


Figure 11. Soil moisture relationships in zone 2 for all treatments at varying soil depths.

the boxes to be accumulated and then pumped outside.

Ten specimens of each species were planted in each of the five moisture zones. The slopes were kept well watered during the period of seedling establishment and dead seedlings were replaced with healthy ones. The seedlings were planted on the slope on February 1, 1976. By February 12, 1976 each zone had 10 individuals of each species established. The formal experiment was started on February 26, 1976 and lasted until June 1, 1976.

In one sandy loam and one silty clay box, the native vegetation was allowed to compete with the seedlings. Figures 12 and 13 show the non-vegetated and vegetated sandy loam boxes respectively. Figures 14 and 15 show the non-vegetated and vegetated silty clay boxes respectively. Figure 16 shows seedlings growing on the bare slope condition of the silty clay soil.

The piezometers and tensiometers were read both before and after watering. From these readings the wetted perimeter and the capillary fringe could be plotted. The height and diameter of each surviving seedling was measured on three occasions during the experiment, March 1, April 1 and June 1, 1976. The data collected during these three measurement periods provided the information used in determining the effects of soil, competition, and moisture regime on the growth of each species.

On June 2, 1976 the seedlings growing on the bare slope boxes were lifted and their root lengths measured and recorded.

A flooding experiment was also conducted using a box 1.2 x 1.2 x 1.2 m with an angle iron frame lined with 3/4 in. plywood (Figure 17). The bottom of the box was made of galvanized steel. The box was tarred to make it watertight. An incandescent lighting rack suspended above the box yielded 2000 ft-c at the top of the box. Lodgepole pine, tamarack,

Figure 12. Bare slope condition of the sandy loam boxes.

Figure 13. Vegetated condition of the sandy loam boxes.

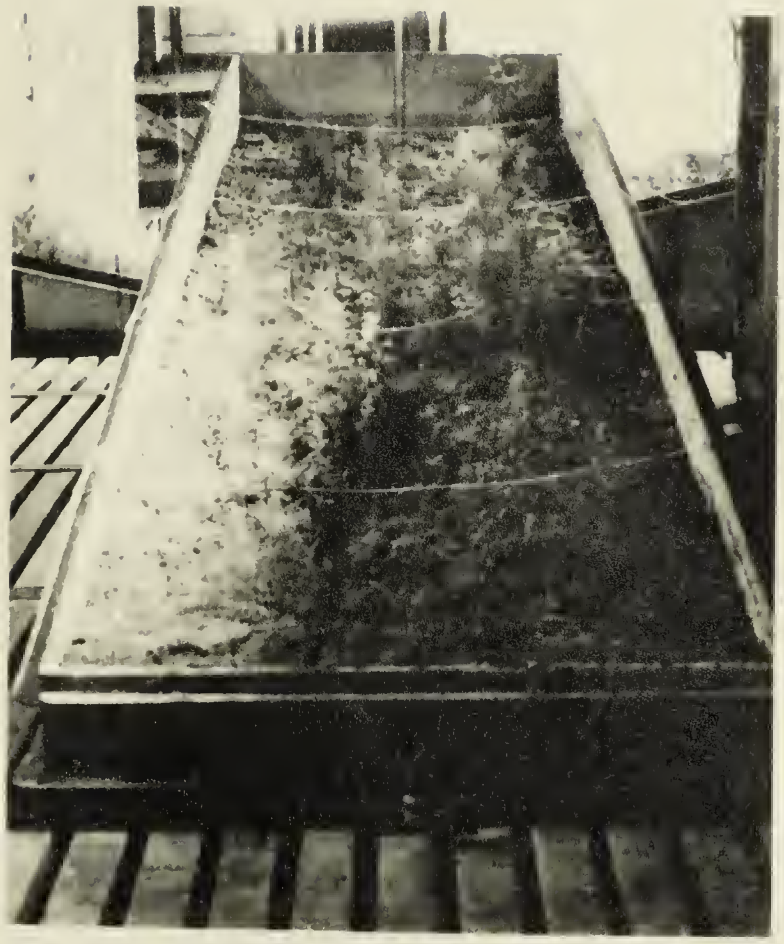


Figure 14. Bare slope condition of the silty clay soil boxes.

Figure 15. Vegetated slope condition of the silty clay soil boxes.

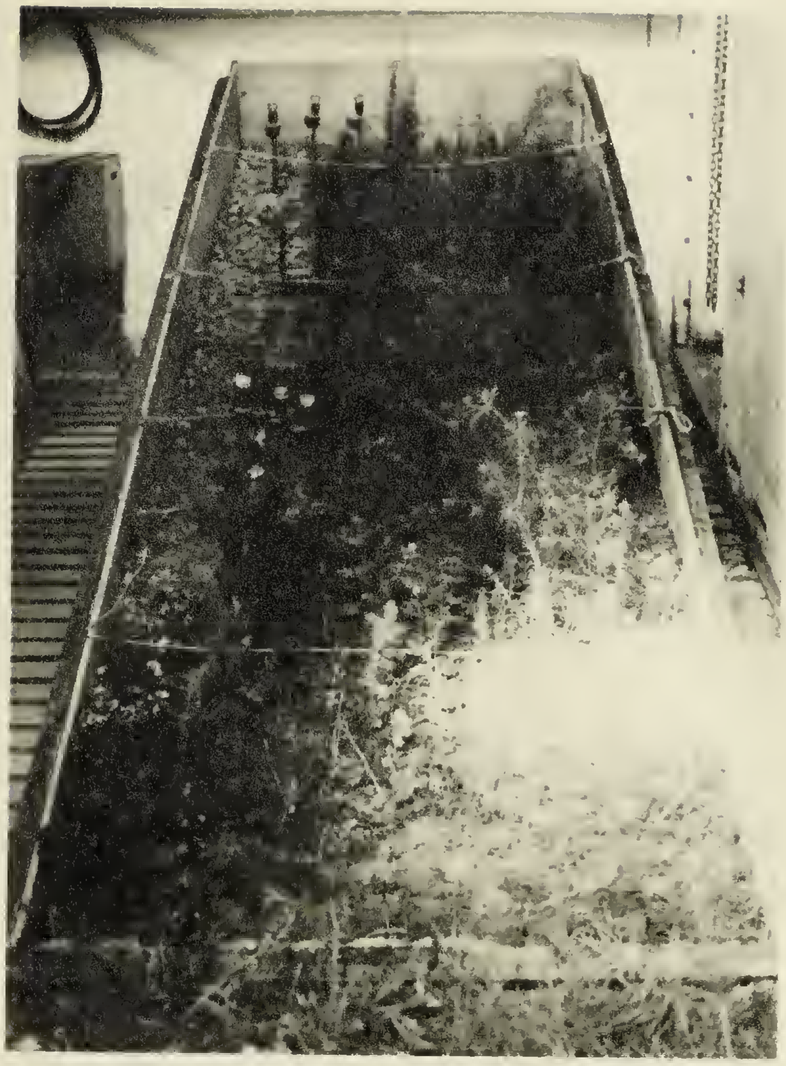


Figure 16. Seedlings growing on the bare slope condition of the silty clay boxes.

Figure 17. Flooding box.


PEN
2

white spruce, black spruce, Siberian larch and Douglas-fir were tested.

There were fourteen trays of seedlings used per run of the experiment. Every tray contained twelve individuals of each species tested. These twelve trays were placed on the bottom of the container, then water was allowed to fill the box until the seedlings were completely submerged. Each day, for ten days, a tray was removed and placed in the University of Alberta's greenhouse where for the next month they were watered and fertilized. One month after each run was completed the percent survival for each species per flooding day was recorded. The temperature of the water was 23°C. At this temperature blue green algae grew on the surface of the water but no other effect due to the water temperature was identified.

3.5 Experimental design.

3.5.1 Survival, diameter growth, and height growth.

The experiment was conducted using a double split plot design with four factors: A - two levels of soil, B - two levels of vegetation, C - five soil moisture levels, and D - ten species (Anderson and McLean, 1974).

Four combinations of A and B acted as whole plot treatments, the five levels of C acted as whole subplot treatments and the ten levels of D were randomized within each of the twelve combinations of A,B, and C (Anderson and McLean, 1974).

3.5.2 Total root length.

A split plot design was used in the analysis for total root length. There were three factors involved: A - two levels of soil, B - five levels of soil moisture levels, and C - ten species.

The combination of levels of A and the five levels of B acted

as whole plot treatments and the ten levels of C were randomized within each of the ten combinations of A and B (Anderson and McLean, 1974).

Due to time restrictions and the expense involved in duplicating the experimental hardware, replication of this experiment was not feasible. Therefore there are no degrees of freedom for the first restriction. Thus the error 1 term was used as the error term for the effect of soil and the effect of vegetation (Anderson and McLean, 1974).

3.6 Tukey test.

Means within interaction tables (Appendix 5) were compared using Tukey's significance test (T.S.D.) (Winer, 1962). The decision to use the Tukey procedure was based on conclusions drawn from recent research on the differences among multiple comparison techniques (Petrinovich and Hardyck, 1969).

3.7 Additional analysis.

Appendix 4, figures 18 through 34 inclusive show the interactions between species and various treatments. These three dimensional graphs reflect the complex relationships that soil textures, soil moisture and competition have on seedlings' survival, diameter growth, height growth, and root length based on experimental results.

The percent survival in the experiment was transformed using the arcsine square root percentage transformation, analyzed, then transformed back to normal percentages (Smillie, 1969), (Anderson and McLean, 1974).

Chapter 4

RESULTS AND DISCUSSION

The results of the analysis of variance are given (Table 3) for survival, diameter growth, height growth, and root length when all species are considered together.

Soil texture had a highly significant effect on survival, diameter and height growth but had no significant effect on root length. The table of overall means (Table 4) shows that higher survival percentages, height and diameter growth occurred consistently on the non-vegetated silty clay soil. Though the effect of soil texture on root length was statistically non-significant the trend was for seedlings grown on silty clay soil to have longer roots than seedlings grown on sandy loam.

The reason growth and survival was best on silty clay soil may be explained by considering the biological and physical parameters of the soil. The Culp soil series (sandy loam) was low in nitrogen, sulfur and phosphorus compared to the Kathleen soil (Table 2). The sandy loam soil had a cation exchange capacity (C.E.C.) one half that of the silty clay soil.

Vegetative competition had a significant effect on survival but no significant effect on height or diameter growth. Root lengths were measured only for bare slope conditions, therefore no information is available on the effect of competition on root growth. Survival with competition was best on the sandy loam soil (Table 4). Growth of seedlings was best on the silty clay soil because of probable greater fertility. Herbaceous growth was also greater on the silty clay soil. The result was denser vegetation on the silty clay soil (Figures 13 and 15). Vegetative competition (Table 1) reduced light, moisture, and

TABLE 3. ANALYSIS OF VARIANCE FOR PERCENT SURVIVAL, HEIGHT GROWTH, DIAMETER GROWTH AND ROOT LENGTH.

Source of variation	d.f.	Percent survival M.S.	Height growth M.S.	Diameter growth M.S.
Soil	1	7231.71**	2466.20**	.303**
Vegetation	1	882.00*	20.68	.002
Soil x Vegetation	1	10205.63**	335.69	.073*
Moisture Zone	4	12335.70**	1355.52**	.091**
Soil x Moisture Zone	4	771.24*	58.97	.009
Vegetation x Moisture Zone	4	323.28	34.23	.005
Error I	4	99.45	88.19	.007
Species	9	4590.81**	2669.50**	.112**
Soil x Species	9	1012.67**	226.00**	.017**
Vegetation x Species	9	306.42*	30.03	.003
Moisture Zone x Species	36	1022.38**	248.98**	.014**
Soil x Vegetation x Species	9	317.14	91.59**	.003*
Soil x Moisture Zone x Species	36	151.82	41.03*	.004
Vegetation x Moisture Zone x Species	36	92.06	13.80	.003
Error II	36	163.85	23.21	.003

Source of Variation	d.f.	Root length M.S.
Soil	1	450.50
Moisture Zone	4	533.95
Error I	4	112.07
Species	9	371.09**
Soil x Species	9	18.71
Vegetation x Species	36	42.60
Error II	36	31.60

* significant at 95% level.

** significant at 99% level.

M.S. mean squares

TABLE 4. MEANS OF PERCENT SURVIVAL, HEIGHT GROWTH, DIAMETER GROWTH AND ROOT LENGTH.

List of Parameters that are Important in the Experiment as determined by A.O.V.	Percent survival (%)	Height growth (cm)	Diameter growth (cm)	Root length (cm)
non vegetated sandy loam soil	61.5	8.68	.09	12.35
non vegetated silty clay soil	80.4	15.7	.17	16.6
standard error of the mean	3.15	3.0	.03	3.35
vegetated sandy loam soil	74.6	12.51	.13	-
vegetated silty clay soil	68	11.87	.13	-
standard error of the mean	1.57	1.48	.01	-
Zone 1 (poorly drained)	53.3	4.61	.09	7.15
Zone 2 (imperfectly drained)	96.3	18.91	.195	17.33
Zone 3 (moderately well drained)	92	16.5	.16	19.9
Zone 4 (well drained)	59	12.51	.135	16.73
Zone 5 (rapidly drained)	39.2	8.42	.08	11.24
standard error of the mean	1.57	1.48	.01	3.35

Continued..

TABLE 4. MEANS OF PERCENT SURVIVAL, HEIGHT GROWTH, DIAMETER GROWTH AND ROOT LENGTH. - Continued.

List of Parameters that are Important in the Experiment	Percent survival (%)	Height growth (cm)	Diameter growth (cm)	Root length (cm)
tamarack	50.3	8.5	.08	8.68
western larch	37.3	23.93	.18	17.47
Siberian larch	66.3	36.69	.3	19.6
lodgepole pine	92.3	4.42	.14	22.3
ponderosa pine	94.1	2.84	.14	23.65
black spruce	69.1	4.71	.06	6.21
white spruce	91.6	4.78	.075	12.56
Douglas-fir	97.2	22.62	.17	14.39
western redcedar	69.5	10.07	.11	11.75
western hemlock	32.4	3.63	.06	8.13
standard error of the mean	4.04	1.52	.02	1.78

nutrients available for seedlings.

Moisture zones had a highly significant effect on all measurements except root length. Survival, height and diameter growth were best overall on zone 2. Zone 2 apparently had an optimal combination of moisture and oxygen. Roots grew best in zone 3.

Table 5 shows how each species responded to the combinations of factors imposed in the study. The table condenses multiple comparison information given in Appendix 5. The species are arranged in order of tolerance to shade (Fowells, 1965). No root lengths were (length of the longest root) measured on the vegetated soils.

Optimum soil moisture levels were determined from the multiple comparisons for survival and height growth in Appendix 5. The effect of competition on seedling survival and growth can be determined by comparing the results for the bare slope to the results for the vegetated slope.

In Table 5, the overall site preference of each species is shown, using survival as an indicator of preference. The habitat preference determined for each species can be related to situations that a forester can recognize in the field.

In regenerating a cutover the most important objective should be to obtain the stocking density required by the local authority. If the area is not stocked to the required density then usually no matter how rapid the growth of survivors are, the ability of the site to yield fiber may fall below the full potential possible.

When a manager is faced with survival and height growth being best on different sites then the need to carefully weigh the economics involved in increasing reforestation costs at present to obtain an acceptable profit from increased future earning is very important.

TABLE 5. OVERALL SITE PREFERENCE OF EACH SPECIES TESTED IN THE EXPERIMENT.

Soil*	Parameters measured	tamarack	western larch	Siberian larch	lodgepole pine	ponderosa pine	black spruce	white spruce	Douglas -fir	western redcedar	western hemlock
NV-SL	survival (%)	57	22.8	44.8	93.2	91.6	52.4	75	75.2	60.8	40.2
	height growth (cm)	5.4	17.4	28.8	7	2.4	2.4	3.4	13	9.8	2
	root length (cm)	7.9	15.8	16.6	20	2.42	5	9.5	10.3	8.4	5.7
NV-SiCL	survival (%)	44.2	62.6	77.2	87.6	92.2	74.4	89	91	74	36.6
	height growth (cm)	11.6	30.5	44.8	4.6	3.4	6.2	6.2	32.4	10.2	5.4
	root length (cm)	9.5	19.1	22.6	24.6	23.1	7.4	15.6	18.5	15.1	10.5
V-SL	survival (%)	47	33.4	71.4	90.2	95.8	64.2	82	86.6	72	40
	height growth (cm)	10.4	24.8	39.4	4.2	2.6	4.2	4.2	21	10.2	3.6
	root length (cm)	-	-	-	-	-	-	-	-	-	-
V-SiCL	survival (%)	54.4	45	54.8	91.2	87.8	61.2	55	71	51	37.2
	height growth (cm)	6.6	23	34	4.2	3.2	4.6	5.4	24.2	10	3.6
	root length (cm)	-	-	-	-	-	-	-	-	-	-
optimum soil moisture level		2	2-3	2-3	no moisture preference	no moisture preference	1-2	2-3	2-3	2	2-3
overall site preference of each species based on survival percentage. Survival is of paramount concern in reforestation consideration		SL-NV-2	SiCl-NV-2-3	SiCl-NV-2-3	SL-NV no moisture preference	SL-V no moisture preference	SiCl-NV-1-2	SiCl-NV-2-3	SiCl-NV-2-3	SiCl-NV-2	SiCl-NV-2-3
effects of competition on height growth		SiCl-NV-2	SiCl-NV-2-3	SiCl-NV-2-3	SL-NV no moisture preference	SiCl-NV no moisture preference	SiCl-NV-1-2	SiCl-NV-2-3	SiCl-NV-2-3	SiCl-NV-2	SiCl-NV-2-3
maximum number of days that a seedling can be submerged and survive		5	-	3	10+	-	6	10+	7	-	-
relative flooding tolerances		most intol.	-	most intol.	most tol.	-	most intol.	most tol.	inter-mediate	-	-

Code used:* SL - sandy loam soil SiCl - silty clay soil NV - non-vegetated V- vegetated

height growth (growth after planting)

On the basis of the economic analysis then the decision on which site to plant the particular species in question can be made.

For all species excepting lodgepole pine, height growth was best on the non-vegetated silty clay soil possibly because it was more fertile than the sandy loam (Wynnyk, Lindsay, and Odynsky, 1969).

Survival and height growth of western larch were best on a non-vegetated silty clay soil with an imperfectly or moderately well-drained moisture regime. This type of site should reduce the difficulties experienced in establishing planted western larch and thus reduce the cost of reforestation.

Past research indicates (Fowells, 1965) that western larch grows best on deep, porous soils that may be sandy, or loamy in texture. However, extensive soil surveys within the type have not been made (Fowells, 1965). This experiment suggests that the species may prefer a more fertile soil such as the silty clay soil. Compared to tamarack, western larch can tolerate and grow well on a drier moisture regime. The two species respond similarly to soil texture and competition.

Survival and height growth of Siberian larch were best on an imperfectly or moderately-well drained, non-vegetated silty clay soil. This would indicate that Siberian and western larch may have similar site preferences in the field.

Lodgepole pine grew best on a non-vegetated sandy loam soil, having no apparent moisture preference. Fowells (1965) has asserted that lodgepole pine survives and grows best on well-drained sites. The means by which lodgepole pine adapts to these very different moisture regimes is not known.

The best survival of ponderosa pine was on vegetated sandy loam

soil with no recognizable soil moisture preference. Height growth for this species was best on a non-vegetated silty clay soil with no apparent soil mositure preference. Fowells (1965) indicated that this species can survive and grow well on either non-vegetated sandy loam or silty clay soils with a well drained soil moisture regime. Better growth on the non-vegetated silty clay soil can be explained on the basis of soil fertility. The reasons ponderosa pine can survive on any moisture regime and under competition are not known.

Survival and height growth of black spruce was best on a poorly to imperfectly drained, non-vegetated silty clay soil. This is in agreement with the results of Fowells (1965).

The best survival and height growth of white spruce occurred on an imperfectly to moderately-well drained, non-vegetated silty clay soil. This is in agreement with the results of other studies (Fowells, 1965).

Survival and height growth of Douglas-fir was best on an imperfectly to moderately-well drained, non-vegetated silty clay soil. No information was found in the literature concerning optimum soil texture for Douglas-fir.

Survival and height growth of western redcedar was best on an imperfectly drained, non-vegetated silty clay soil. These results agree with the literature (Fowells, 1965).

Western hemlock survived best on an imperfectly to moderately-well drained, non-vegetated sandy loam. Height growth was best on a non-vegetated, imperfectly to moderately-well drained soil. The literature states that western hemlock does best on well drained organic soils with or without vegetation competition (Fowells, 1965).

Fowells (1965) indicated that western hemlock prefers a well

drained organic soil. This does not agree with the finding of this study which indicates western hemlock prefers imperfectly to moderately well drained mineral soils. Organic soils were not tested in this study. However, organic soil could perhaps allow better growth of western hemlock as the following discussion indicates.

Organic soils have high water-holding capacities (Buckman and Brady, 1969). While a dry mineral soil will adsorb and hold from one-fifth to two-fifths its weight in water, an organic soil will remain three or four times its dry weight as moisture, depending on surrounding environmental conditions such as air temperature, insolation, and vegetation growing on these soils (Buckman and Brady, 1969).

Two conditions mitigate against the organic soils. Firstly the amounts of unavailable water are much higher proportionately than those of mineral soils and secondly organic soils have low bulk densities (Buckman and Brady, 1969). However, when considered on a volume basis a given layer of organic soil at optimum moisture will supply somewhat more water to plants than a representative mineral soil, also at optimum moisture (Buckman and Brady, 1969).

Usually within the wet to dry western hemlock biogeoclimatic zones, rainfall is plentiful and evaporation due to high soil temperature is not a serious problem thus organic soils do provide better sites for western hemlock when moisture availability is considered (Packee, 1974).

The previous discussion supports the comment made in the introduction on page 2 that within Forest Regions the given tree species exhibit remarkable flexibility in site preferences. A given site type might be repeated in each of the Regions, but for reasons of species migration and isolation, no one tree species occupies all sites optimally

suited for them. Keeping the two previous statements in mind, a grouping of species by site preferences may reflect the flexibility that seems to be inherent in them.

Table 5 shows that western larch, Siberian larch, black spruce, white spruce, Douglas-fir and western redcedar had nearly identical site preferences. Also in Table 5, ponderosa pine and lodgepole pine could be grouped together, as could tamarack and western hemlock, as these associations reflect similar site preferences of the species embodied within each group. Extension of a species from one region to the next may therefore, be quite feasible and would allow greater flexibility in choosing species to plant within each Forest Region.

The grouping of species according to similar site preferences allows a general discussion of how a species succeeds in establishing individuals within these optimum niches and how environmental and soil parameters influence the migration of these species into new Regions.

In western Canada, boundaries of each Forest Region are directly influenced by geographic barriers (Rowe, 1972). The boundaries of the Columbia, Montane, Subalpine, and Boreal Forest Regions are either completely or partially limited by mountain ranges. Where a mountain range yields to relatively flat uniform topography, as in the Boreal Forest, a large geographic area can be covered by the same species. When mountain ranges are close to each other the corresponding geographic distribution of a Forest Region is considerably reduced.

The reasons for this relationship can be explained by considering the genetics of forest ecosystems. Trends in the mean values of climatic factors are distinct for mountain slopes, particularly for large geographic areas. Characters that are subject to direct or

correlated selection often reflect the trends in environmental factors, as they vary clinally. In most cases, long-term averages of climate constitute inadequate measures of environmental influences along such gradients. Substantial year-to-year deviations from the mean are often of considerable significance for the success of the individual during a short developmental phase, which may determine its potential to survive and reproduce. For this reason climatic influences on a species would be better understood by considering the niche frequency along the gradient (Stern and Roche, 1974). For example, the length of the growing season, which is taken to begin when the temperature sum reaches a certain level in the spring and to finish when a critical day length is reached in the autumn, reflects the influence of environmental factors on a species population. In many cases adaptation to the length of the growing season also depends upon early and late frosts. Thus at least four niche factors instead of one should be considered: date and distribution of the temperature sum needed to initiate growth, frequency and distribution in time of spring frosts, date of the critical day length in the fall, and frequency and distribution in time of early frost in the fall (Stern and Roche, 1974). Only one of these factors is constant; the remaining three vary from year to year. The effects of the first two are not independent of each other, because the damage resulting from a spring frost at a certain date is also determined by the date when the necessary temperature sum was reached. Therefore, to describe this part of the environment adequately, in addition to mean values of climatic factors, attention should be given to their local heterogeneity, and better still, to the geographic trends of this heterogeneity (Stern and Roche, 1974).

The importance of soil properties as niche factors is much less

well known than that of climatic factors, if one disregards obvious cases such as niche limitation through extremes of moisture and ion concentration. Correlations between soil properties and adaptive characters or characters associated wtih adaptation have been much less frequently described than correlations between climatic factors and adaptive characters (Stern and Roche, 1974).

Presumably soil influences should be reflected in characteristics of the rooting system. Thus one would expect adaptations to become evident as differences in gross morphology such as shallow root, heart root, and tap root to denote major distinctions. The Europeans have claimed that a mixture of shallow- and deep-rooted species offers optimal utilization of soil capacity through reduced competition in the rooting sphere in the same way as the combination of fast-growing intolerant species with slower tolerant species is beneficial in crown space (Stern and Roche, 1974). There are, in fact, indications that similar differences in root structure exist among genotypes of the same population and that these differences contribute to competitive ability and competitive influence (Stern and Roche, 1974).

The limits of the area occupied by a species are often boundaries determined by competition. The species might be very well capable of living and reproducing outside of these boundaries but is prevented from doing so by more competitive populations of other species (Stern and Roche, 1974).

In the Boreal Forest, along the foothills of Alberta, populations of Douglas-fir, western redcedar and western larch have invaded from the Montane and Columbia Forest Regions and white spruce, black spruce, tamarack, and lodgepole pine have invaded the Montane and

Columbia Forest Regions from the Boreal Forest Region. Similarly western hemlock has invaded parts of the Columbia Forest Region. These examples of migration of various species into fringes of different Forest Regions lends support to the previous discussion. However, the genetic potential of individuals from these fringe populations is not well understood (Stern and Roche, 1974).

Populations at the edge of the range of a species are exposed to different environmental conditions than those in the centre. "Edge" in this sense means a boundary area where a tree species is limited by some extreme factors such as are found near the tree limit of the far north, in the high mountains, or in arid zones (Stern and Roche, 1974). The range may further be limited by geographic barriers or by competitive superiority of other species where the species could normally thrive without such competition.

High selection intensities characterize the conditions under which such marginal populations exist. Selection in the far north or high elevations is mainly for adaptation to extremely short growing seasons and low winter temperatures, including all accompanying factors such as winter drought. Immigrants from the center of the range will therefore always possess lower fitness, and if they establish themselves in the marginal population, reduce rather than increase its adaptive value. Directional selection thus prevails in marginal populations whereas stabilizing and/or diversifying selection determine evolution in the central populations. The role of competition with other species often diminishes because only a few species are capable of surviving in extreme conditions near the limits of forests and tree growth. Intraspecific competition occurs here at a comparatively low level since

one or more environmental factors such as temperature and humidity are at a minimum. Stands in such marginal forest areas are therefore often characterized by low density (Stern and Roche, 1974).

Causes of rapid evolution of the marginal population means are due to the invasion of new niches, isolation, founder effects, and possibilities of developing new forms of coadaptation (Stern and Roche, 1974).

Thus a good possibility exists for extending the range of species used in the experiment into adjacent Forest Regions. The site preferences determined in Table 5 and the grouping of species on the basis of similar niche requirements show that there is great flexibility in site preference of all species tested. This translates into the real possibility that the ranges of species could be extended. Establishing plantations of various genotypes of marginal populations in adjacent Regions on preferred sites and accelerating tree genetic research is urgently needed in order to provide forest managers with better forests, hence higher fiber yields.

Site variability within cutblocks, which causes high reforestation costs due to monoculture techniques currently being used, could be alleviated by planting particular sites with suitable species. For a manager to try to plant a cutover with several species in order to obtain good stocking, he would need to carefully assess the increased costs involved in planting. The increased cost should be offset by increased profit earned by better growth of timber on the cutover. If costs proved prohibitive then the current systems in use should be continued until research discovers a method to make this proposal profitable.

Possibly an alteration of cutblock shape to reflect closer uniformity in site preferences throughout the cutover would lower reforestation costs. The problem exists that planting several species on a cutover could possibly influence rotation age and method of logging. Only economic analysis could show whether or not the above changes in current reforestation and logging practices would be profitable.

Table 13 shows the results of the flooding experiment. Siberian larch only survived three days of flood, tamarack survived five days, black spruce six days, Douglas-fir seven days, and lodgepole pine and white spruce more than ten days of flooding. This experiment was conducted in order to assess the relative flooding tolerance of each species tested. This information could help influence modification of scarification techniques to reduce the possibility of flooding in the field situation over the growing season. The species tested are often planted or occur naturally on sites that may be subject to periodic flooding.

One possible reason why tamarack and black spruce are intolerant, and Douglas-fir is intermediate to flooding, is probably due partly to the physiology of these species plus the inability of black spruce and tamarack root systems to function well under flooded conditions. Tamarack and black spruce tolerate high water tables by developing shallow root systems to take advantage of the thin well-aerated layer above the permanent water table. These species are forced onto these sites because of their inability to compete successfully with other species, like white spruce, but these two species do not necessarily prefer high water table sites.

Chapter 5

SUMMARY AND CONCLUSIONS

Considerable new knowledge has been gained through this study. The void areas in Table 1 represented possible areas for future research. Table 6 is the same as Table 1 with the results from this study added to it. Not enough is known to fill in Table 6 completely, but we know much more about the general site requirements of the ten conifers under study than previously.

General conclusions are:

1. Non-vegetated silty clay soil yielded the best survival, height and diameter growth when all species are considered together.
2. Overall site preferences for each species tested are:
   a) tamarack and western redcedar; survival and height growth - an imperfectly drained, non-vegetated silty clay soil.
   b) western and Siberian larch, white spruce, and Douglas-fir; survival and height growth - an imperfectly or moderately well-drained, non-vegetated silty clay soil.
   c) lodgepole pine; survival and height growth - a non-vegetated sandy loam with no apparent soil moisture preference.
   d) ponderosa pine; survival - a vegetated sandy loam with no apparent soil moisture preference. Height growth - a non-vegetated silty clay soil with no apparent moisture preference.
   e) black spruce; survival and height growth - a poorly or imperfectly drained, non-vegetated silty clay soil.

3. Establishment of Siberian and western larch was poor. Once established, however, growth was superior to all other species tested.

4. Relative flooding tolerance for flushed seedlings showed that tamarack, Siberian larch and black sprcue was very intolerant to flooding for periods up to 10 days. Douglas-fir was intermediate in tolerance and white spruce and lodgepole pine were very tolerant to the flooding treatment.

TABLE 6. ADDITIONS TO CURRENT KNOWLEDGE OF THE SILVICS OF THE TEN CONIFEROUS SPECIES.

Environmental Parameters considered in the experiment	Generalized Relationships	Siberian larch	Douglas-fir	Western larch	Western redcedar	Tamarack	Black spruce	White spruce	Lodgepole pine	Ponderosa pine	Western hemlock	References
Soil texture	Optimal soil texture	silty clay or fine textured soils	silty clay or fine textured soils	gravelly, loamy or sandy soil	silty clay or fine textured soil	heavy clays or coarse sandy	loams or sandy loam soils, silty clay	loam soils, silty clay	silty clay to clay loam soils sandy loam	sandy loam, gravelly loam, clay loam, loamy soil, and gravel.	organic soils, silty clay or sandy loams	(Fowells, 1965)
Soil tension	1, 6 and 15 atmospheres tension have no effect on height growth		Over 20 atmospheres tension, transpiration drops to 17% of maximum					Cessation of photosynthesis occurs at 9 atmospheres. Over 20 atmospheres tension, transpiration drops to 2 - 5 percent of maximum.		Over 20 atmosphere tension, transpiration drops to 2-5 percent of maximum.		(Glerum and Pierpoint, 1968) (Lopushinsky, 1969) (Zavitkovski and Ferrell, 1968)
Light intensities and shade ratings	Optimal light intensities		Intermediate	Intolerant except in seedling stage where tolerant	very tolerant	very tolerant	tolerant	tolerant - reaches maximum photosynthesis at 5,000 ft-c.	intolerant - not light saturated at 12,000 ft-c.	intolerant - not light saturated at 12,000 ft-c.	very tolerant	(Baker, 1949) (Brix, 1972) (Cochran, 1972) (Fowells, 1965) (Pearson, 1950)
Moisture drainage class and moisture regime	Optimal drainage	Imperfectly or moderately well drained	Well drained under heavy rainfall	well drained	imperfectly drained under high rainfall	imperfectly drained	poorly or imperfectly drained	imperfectly drained - mesic condition	well drained - no apparent moisture preference	well drained - no apparent moisture preference	well drained under high rainfall	(Fowells, 1965) (Rowe, 1955)
Competition	Vegetative competition monopolizes available light, space and soil moisture, and may cause mechanical damage	Prefers no vegetative competition	Responds satisfactorily to release from competition up to 100 years old	on mineral soil without competition growth is twice as fast for at least 15 years	Growth is retarded in proportion to the density of the shade	very unsuccessful in competing with other vegetation	seedlings will develop under competition with as little as 10 percent of full light. Superior development occurs in the open.	70 percent or better vegetation canopy reduces height growth considerably	reduces growth considerably	reduces growth considerably. Seedlings on bare soil show eleven fold greater gain in dry weight than those grown with vegetative competition	survives a very long time and even reaches maturity under competition but responds well to release	(Crossley, 1969) (Fowells, 1965) (Meyer, 1937) (Mullin, 1969) (Pearson, 1950) (Place, 1955) (Wagg, 1973)
Flooding	Effects of flooding on certain species are shown. Flooding implies seedling submersion	intolerant	intermediate			A fluctuating water table causes mortality. Intolerant	intolerant to intermediate	Factors resulting in mortality are: - scarification techniques causing ponding. Tolerant	tolerates high water table but does not grow. - radial swelling - shallow rooting Tolerant	tolerates high water tables but growth is very slow. - radial swelling - shallow rooting		(Cochran, 1972) (Denyer and Riley, 1964) (Lees, 1964)

* box items represent new additions to the literature as a result of this study.

Chapter 6

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APPENDIX 1

Information on seed sources for species tested.

TABLE 7. SEED SOURCE INFORMATION.

	Western redcedar	Douglas-fir	Western hemlock	white spruce	lodgepole pine
Location	50^{o} 50' latitude 119^{o} 30' longitude	49^{o} 14' latitude 115^{o} 26' longitude	51^{o} 01' latitude 118^{o} 02' longitude	Sec 29, TS 103, R 19, W 5.	TS 65, R 7, W6.
Date collected	November 19, 1971	November 5, 1974	November 7, 1974	August 28, 1968	July, 1974
Registration or seedlot number	82L13/03/2534/3.6	8263/B3/2443/5.0	82M1/B3/2449/2.5	DF1-2-68	PG65-7-6-74
Tree age from which cones were collected	40 yrs and older	40 yrs and older	100 yrs and older	40-100 yrs old	40-100 yrs old
Aspect of stand	southwest	south	north	--	northeast
Elevation limits in feet	3500-3800	4700-5200	2500	--	1000
Associated species in stand	--	Ponderosa pine and western larch	--	white spruce	aspen
Method of collection	hand felling and picking	felled trees	--	handpicked from logging slash	handpicking
Condition of cones when shipped	good	good/dry	mature	closed	green
Date of extraction	November 19, 1974	November 5, 1974	November 7, 1974	August 27, 1974	October 22, 1968
Yield/bushel	.557 kg	.341 kg	.301 kg	2.7 oz	19 oz
Moisture content when stored in percent (ovendry weight)	4.9	6.3	4.6	6.8	81.1
Seed/pounds	--	--	--	124,437	206,388
Purity by weight (in percent)	99.7	99.9	99.8	90	98.66

TABLE 7. SEED SOURCE INFORMATION (Continued)

	black spruce	tamarack	western larch	ponderosa pine	Siberian larch
Location	53^o 47' latitude 108^o 35' longitude	53^o 50' latitude 108^o 40' longitude	49^o 30' latitude 119^o 30' longitude	46^o 55' latitude 117^o 35' longitude	TS 53, K 23, W 4.
Date collected	1971	1971	September 3, 1974	--	September 14, 1974
Registration or seedlot number	--	--	82E11/B3/2506/3.7	--	S1B1-74
Tree age from which cones were collected	--	--	100 yrs and older	--	40-100 yrs old
Aspect of stand	--	--	southeast	--	level
Elevation limits in feet	--	--	3450-3950	--	--
Associated species in stand	--	--	--	--	--
Method of collection	--	--	felled trees	--	hand
Condition of cones when shipped	--	--	good	--	good
Date of extraction	--	--	November 1, 1974	--	--
Yield/bushel	--	--	.32 kg	--	--
Moisture content when stored in percent (ovendry weight)	--	--	6.8	--	--
Seed/pound	--	--	--	--	40.8
Purity by weight (in percent)	--	--	98.6	--	--

APPENDIX 2

Profile descriptions of the Kathleen and Culp soil series.

Soil profile descriptions for soils used in the experiment.

A) Kathleen Series - Orthic Gray Luvisol:

Kathleen soils typically have a thin leaf mat overlaying a thick grayish leached horizon. The subsurface horizon is fine-textured with a blocky structure and a characterisitcally brown color. Depth of development is between 20 and 30 inches. A description of a representative Kathleen soil profile is (Wynnyk, Lindsay, and Odynsky, 1969).

Horizon	Thickness in.	cm.	Description
L - H	2	5.0	very dark grayish brown (IDYR 3/2), leaf litter. pH 6.6.
Ae	3	7.5	pale brown (10 YR 613) silt loam fine platy, firm. pH 6.3.
AB	3	7.5	brown (10 YR 5/3) silty clay loam, subangular blocky, firm. pH 5.2.
Bt	8	20.0	brown (10 YR 4/3) clay, blocky, very firm. pH 5.0.
BC	5	12.5	dark brown (10 YR 3/3) silty clay, subangular block, firm. pH 6.6.
Ck	at 21,	at 52.5 below surface	dark brown (10 YR 3/3) silty clay that may have yellowish brown (10 YR 5/6) silt laminae. Moderately calcareous, pH 7.8.

Kathleen soils are quite uniform in depth of profile development but they show variations in the structural development of their Bt horizons. The consistency and structure of these horizons ranges from firm blocky to very firm-subangular blocky. The parent materials of these soils range in texture from silty clay loam to silty clay, in color from dark brown to very dark grayish brown, and in degree of stratification from numerous laminae to none.

Particle size analysis conducted on the Kathleen soil (mixed A and B horizons) used in the experiment showed 27 percent sand, 25 percent silt and 48 percent clay. This agrees with particle size analysis carried out for Kathleen B horizon when the soil surveys of this area were conducted. (Wynnyk, Lindsay, Odynsky, 1969).

B) Culp soils - Orthic Gray Luvisols.

Culp soils have a thin layer of leaf litter resting on a relatively thick, grayish, leached horizon. The subsurface horizon is yellowish brown in color, has a sandy texture and may be characterized by clay bands of variable thickness. The depth of profile development is from 20 to 30 inches. A description of a representative Culp soil profile is (Wynnyk, Lindsay, Odynsky, 1969).

Horizon	Thickness in.	Thickness cm.	Description
L - H	2	5.0	dark brown (10 YR 3/3), leaf litter. pH 6.2.
Ae	5	12.5	light yellowish brown (10 YR 6/4) loamy sand, weak platy, friable. pH 6.0.
AB	4	10.0	yellowish brown (10 YR 5/4) sandy loam, weak subangular blocky, firm. pH 6.0.
Bt	8	20.0	yellowish brown (10 YR 5/4) sandy clay loam, subangular blocky, firm. pH 5.8.
BC	8	20.0	brown (10 YR 5/3) sandy loam often with sandy clay loam laminae, weak granular, firm. pH 6.5.
Ck	at 27, below surface	at 67.5 below surface	grayish brown (10 YR 5/2) sandy loam with strata of loamy sandy and often laminae of sandy clay loam, weakly calcareous. pH 7.6.

Culp soils have relatively thick Ae horizons that often show additional development within themselves. This development has presently not advanced to the stage where the soils could be classified in the Bisequa subgroup. The Bt horizons of these soils may show varying degrees of banding. This banding is both pedogenic and depositional.

Culp soils are rapidly drained, need N,S,P fertilizer to increase productivity, water storage is low and there is no salinity problem. Culp soils also exhibit high permeability.

Particle size analysis conducted on the Culp soil (mixed A and B horizons) used in the experiment showed 70 percent sand, 12 percent silt, and 18 percent clay. The soil survey report states that a B horizon for Culp contains 66 percent sand, 17 percent silt, and 20 percent clay (Wynnyk, Lindsay, Odynsky, 1969).

APPENDIX 3

Means of the raw data.

TABLE 8. AVERAGED MEANS OF THE RAW PERCENT SURVIVAL DATA FOR EACH SPECIES PER TREATMENT PER SOIL MOISTURE ZONE.

Species No.	1	2	3	4	5	6	7	8	9	10
Box 1 Sandy loam soil, vegetated:										
Zone 1	80	50	100	100	30	60	30	0	60	90
Zone 2	100	100	100	100	100	100	100	80	90	100
Zone 3	80	100	100	100	100	100	80	50	80	80
Zone 4	40	80	100	100	80	90	20	0	60	20
Zone 5	0	80	100	100	30	80	0	0	60	0
Box 2 Sandy loam soil, non-vegetated:										
Zone 1	80	0	70	50	10	0	20	0	0	80
Zone 2	100	100	50	70	100	100	80	60	50	100
Zone 3	60	100	100	90	70	100	60	30	60	100
Zone 4	0	90	90	70	0	40	0	10	30	0
Zone 5	0	70	70	70	0	0	0	0	0	0
Box 3 Silty clay soil, non-vegetated:										
Zone 1	100	50	50	60	70	50	10	30	30	60
Zone 2	100	100	50	80	100	100	50	80	100	80
Zone 3	70	100	70	100	100	100	50	70	100	10
Zone 4	40	100	70	100	80	100	30	40	70	10
Zone 5	40	100	90	80	30	80	0	30	50	20
Box 4 Silty clay loam, vegetated:										
Zone 1	100	40	70	80	60	70	60	80	80	70
Zone 2	100	100	100	100	100	100	60	100	100	100
Zone 3	100	100	100	100	100	100	80	100	100	60
Zone 4	40	100	100	100	70	100	20	40	70	30
Zone 5	40	100	100	100	30	100	0	30	70	70

Species code:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

TABLE 9. AVERAGED MEANS OF THE RAW HEIGHT GROWTH DATA FOR EACH SPECIES PER TREATMENT PER SOIL MOISTURE ZONE (CM).

Species No.*	1	2	3	4	5	6	7	8	9	10
Box 1 Sandy loam soil, vegetated:										
Moisture zones:										
Zone 1	0.03	1.5	0.7	0.7	-0.1	2	0.5	0	2.7	0.4
Zone 2	3.2	2	1.1	1	20.36	3.3	2	26.9	42.7	13.95
Zone 3	2.3	2.79	1.1	0.5	16.4	19.05	6.25	36	35.75	6.6
Zone 4	1.1	1.65	0.75	2.2	10.95	22.7	0.85	0	34.95	0.05
Zone 5	0	0.75	0.75	2.6	9.2	18.3	0	0	26.7	0
Box 2 Sandy loam soil, non-vegetated:										
Zone 1	2.3	0	1.2	2.2	0	0	2.65	0	0	2.17
Zone 2	13.1	6.4	5.2	3.04	26.3	6.7	1.4	43.05	57.3	18.5
Zone 3	4.65	7.8	3.2	3.5	16.3	26.4	5.6	44.3	45.67	12.85
Zone 4	0	7.6	2.7	4.33	0	31.25	0	23.16	40.7	0
Zone 5	0	4.6	1.4	5.06	0	0	0	0	0	0
Box 3 Silty clay soil, non-vegetated:										
Zone 1	10.9	4.6	6.85	4.2	2.7	7.6	1.9	28.3	9.5	11.6
Zone 2	13.6	11.1	11.4	5.45	21.7	33.3	6.1	60.2	70.85	24.2
Zone 3	8.04	6.3	8.5	2.5	12.5	27.4	9.65	42.7	64.3	6.5
Zone 4	3.65	2.8	7.2	4.7	4.9	38	9.6	32.75	61.4	22.1
Zone 5	0.15	5.6	7.6	2.5	4	39.8	0	21.8	45	17.9
Box 4 Silty clay loam, vegetated:										
Zone 1	11.55	1.95	2.1	3.1	7.1	7.75	4.5	19	15.8	4.35
Zone 2	9.9	8.1	6.5	2.3	28.1	38.5	5.3	39.6	45.5	17.2
Zone 3	3.3	7.5	3.75	1.9	11.7	41.7	8.75	34.2	55.6	6.1
Zone 4	0.13	6.2	8.9	3.3	5.1	34.45	7.6	14.75	42.5	5.6
Zone 5	0.3	6.3	7.5	1.8	4.1	54.2	0	11.95	36.8	0

* See table 8 for explanation.

Table 10. AVERAGED MEANS OF THE RAW DIAMETER GROWTH DATA FOR EACH SPECIES PER TREATMENT PER SOIL MOISTURE ZONE (CM.)

Species No.*	1	2	3	4	5	6	7	8	9	10
Box 1 Sandy loam soil, vegetated:										
Moisture zones:										
Zone 1	0	0.03	0.01	0.4	-0.01	0.01	0	0	0.01	0
Zone 2	0.06	0.06	0.08	0.03	0.11	0.02	0.01	0.17	0.37	0.13
Zone 3	0.03	0.12	0.13	0.01	0.07	0.04	0.04	0.24	0.32	0.05
Zone 4	0.04	0.01	0.06	0.08	0.07	0.1	0.014	0	0.25	0.06
Zone 5	0	0	0.066	0.03	0.06	0	0	0	0.22	0
Box 2 Sandy loam soil, non-vegetated:										
Zone 1	0.05	0	0.09	0.1	0.06	0	0.105	0	0	0
Zone 2	0.146	0.1	0.22	0.14	0.24	0.12	0.05	0.231	0.38	0.168
Zone 3	0.05	0.17	0.18	0.13	0.24	0.18	0.13	0.255	0.46	0.09
Zone 4	0	0.08	0.07	0.22	0	0.22	0	0.256	0.46	0
Zone 5	0	0.06	0.13	0.14	0	0	0	0	0	0
Box 3 Silty clay soil, non-vegetated:										
Zone 1	0.1	0.11	0.24	0.2	0.08	0.17	0.13	0.25	0.11	0.17
Zone 2	0.13	0.15	0.22	0.21	0.22	0.39	0.11	0.39	0.69	0.22
Zone 3	0.12	0.14	0.23	0.09	0.1	0.3	0.11	0.26	0.39	0.06
Zone 4	0.07	0.07	0.33	0.21	0.09	0.3	0.03	0.22	0.45	0.17
Zone 5	0.01	0.07	0.13	0.2	0.04	0.26	0	0.17	0.38	0.115
Box 4 Silty clay loam, vegetated:										
Zone 1	0.07	0.06	0.22	0.17	0.21	0.13	0.06	0.23	0.15	0.07
Zone 2	0.1	0.11	0.13	0.11	0.34	0.39	0.09	0.39	0.38	0.18
Zone 3	0.116	0.07	0.07	0.06	0.19	0.28	0.1	0.23	0.38	0.13
Zone 4	0.06	0.01	0.23	0.13	0.05	0.3	0.15	0.12	0.33	0.1
Zone 5	0	0.07	0.1	0.15	0	0.26	0	0.13	0.3	1

* See table 8 for explanation.

TABLE 11. AVERAGE MEANS OF THE RAW TOTAL ROOT LENGTH DATA FOR EACH SPECIES PER TREATMENT PER SOIL MOISTURE ZONE (CM).

Speces No.*	1	2	3	4	5	6	7	8	9	10
Box 2 Sandy loam soil, vegetated:										
Moisture zones:										
Zone 1	4	5	8.4	10	13	0	6.5	0	0	5.5
Zone 2	11.9	7	19.2	23.14	15.2	9.9	7.75	17	29	14.6
Zone 3	9.3	13.5	21.3	33	14	17.9	14.5	36	32.7	19.4
Zone 4	0	14	25.5	29.4	0	23.75	0	26	21.5	0
Zone 5	0	8	25.43	25.3	0	0	0	0	0	0
Box 3 Silty clay loam, non-vegetated:										
Zone 1	56.66	52.48	57.8	56.48	55.98	45.8	48.16	57.75	55.24	59.15
Zone 2	57.48	55.43	58.76	57.54	60.13	57.48	56.98	59.67	62.65	60.13
Zone 3	58.24	54.82	58.05	58.18	58.5	58.24	58.24	60.4	56.6	42.53
Zone 4	64.01	54.94	57.1	58.24	58.5	58.69	58.95	60.13	57.99	61.89
Zone 5	53.79	54.88	58.24	58.89	41.78	42.36	0	59.8	56.54	60.8

* See table 8 for explanation.

APPENDIX 4

Three dimensional figures showing the relationship between species, boxes, and growth increments per zone.

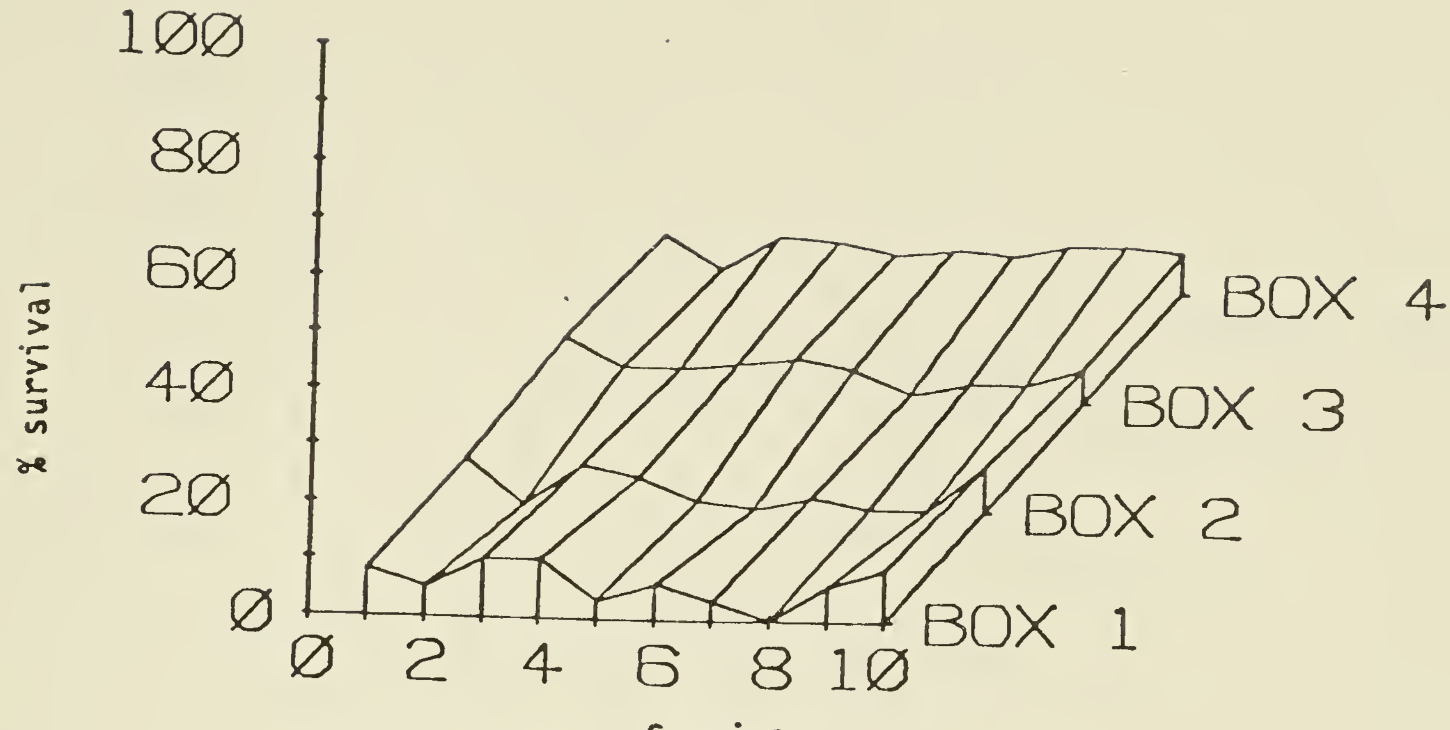

Figure 18. Percent survival for zone 1.

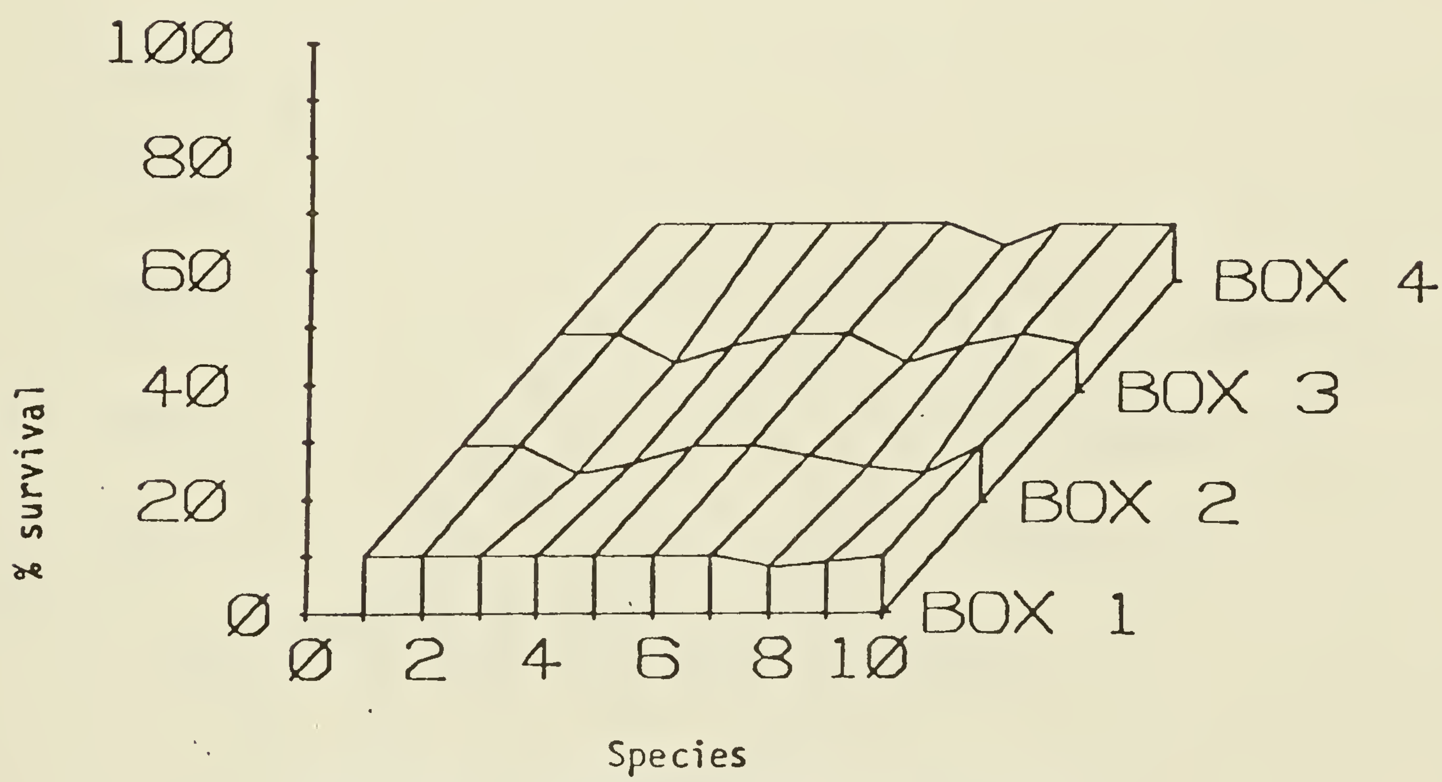

Figure 19. Percent survival for zone 2.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

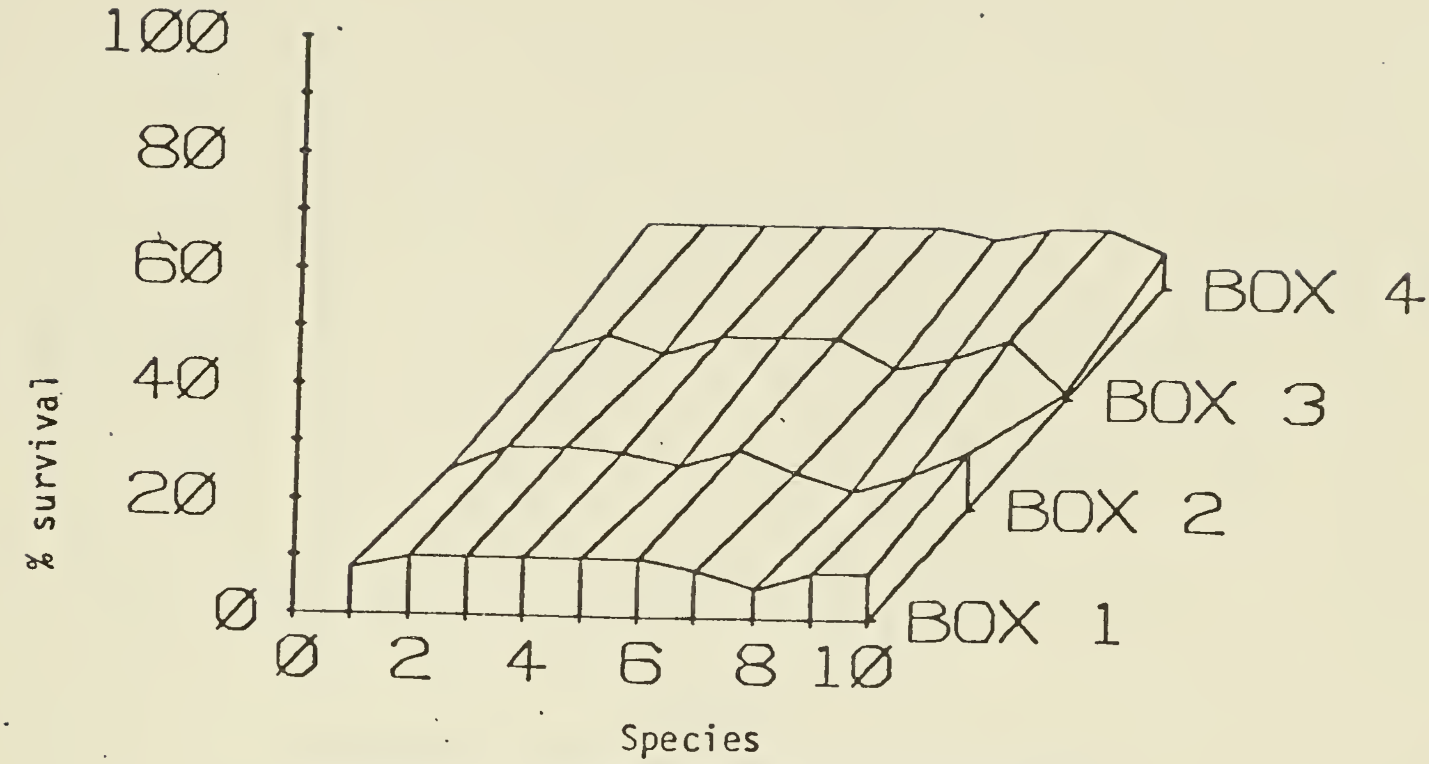

Figure 20. Percent survival for zone 3.

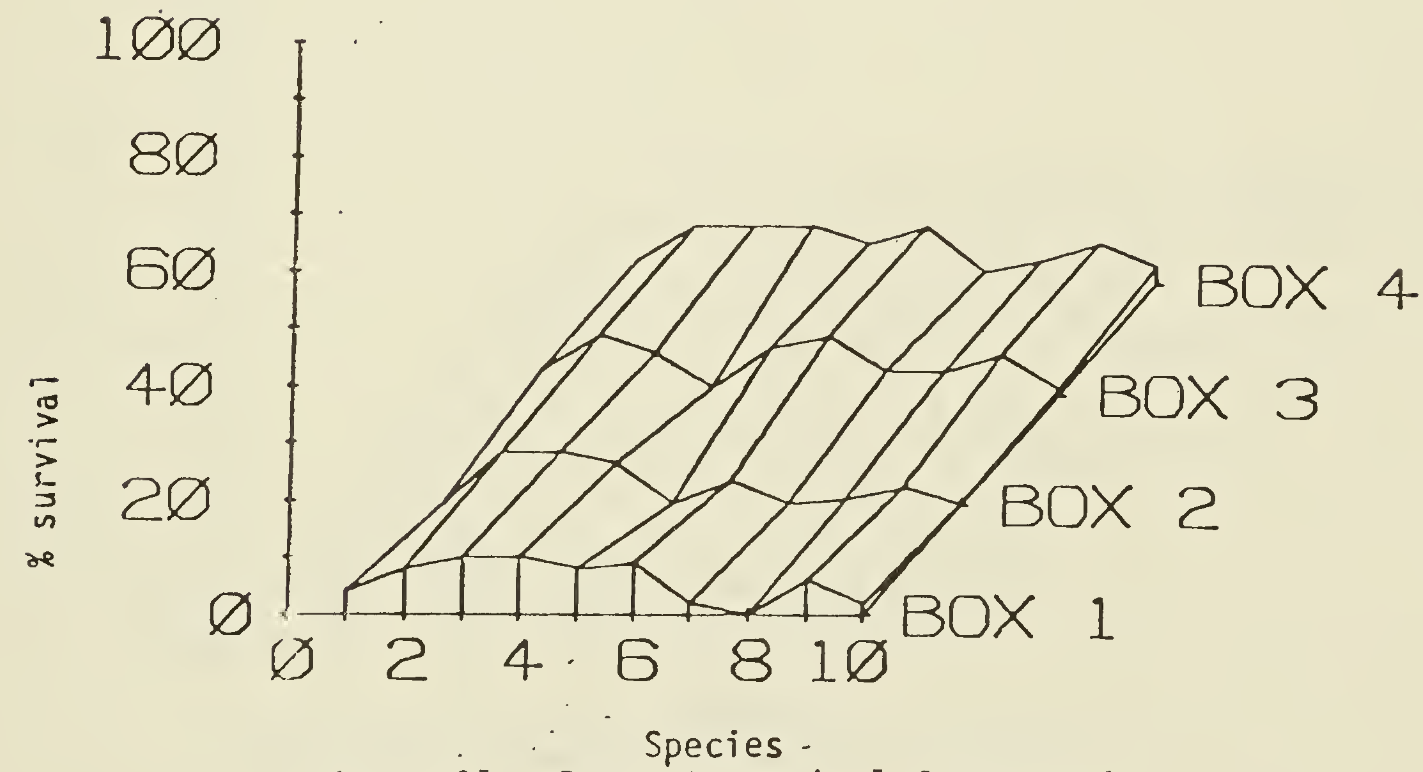

Figure 21. Percent survival for zone 4.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

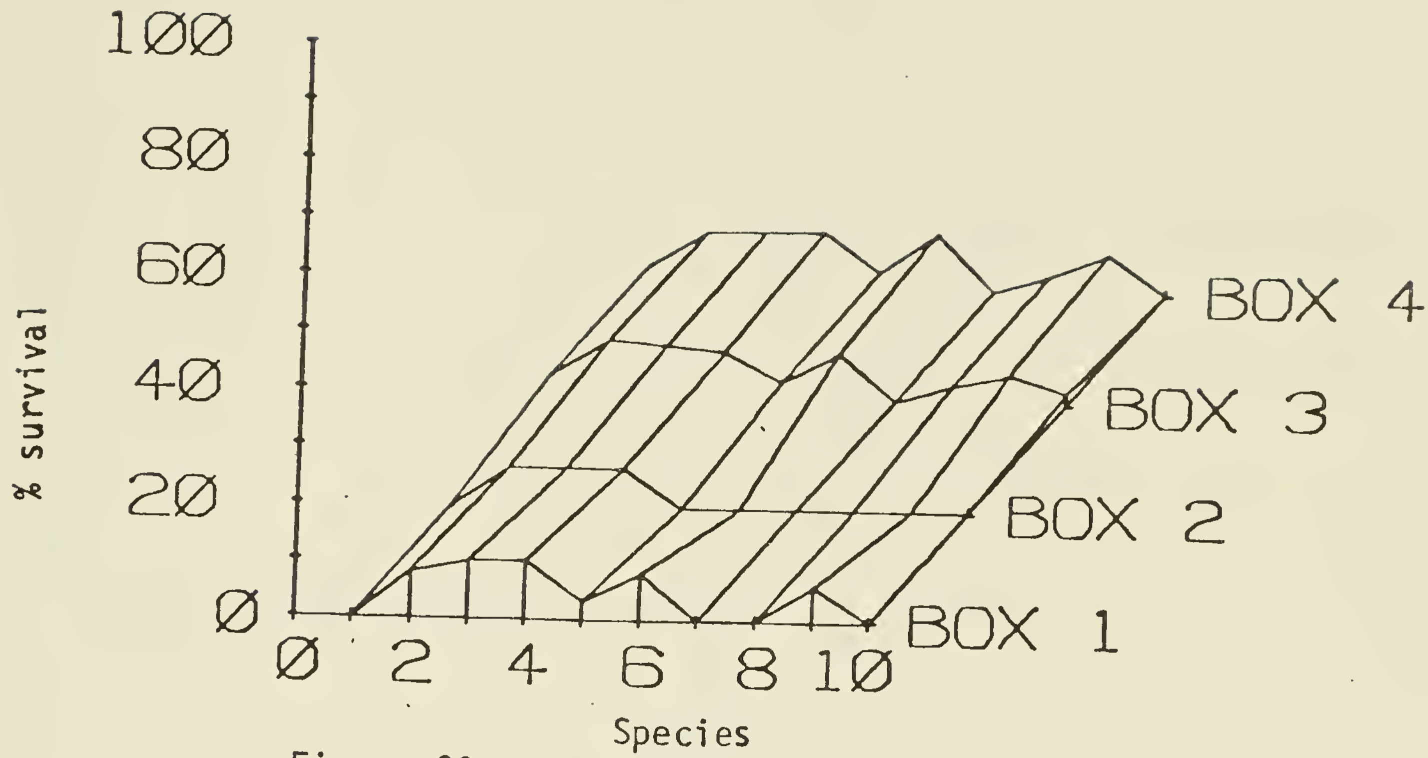

Figure 22. Percent survival for zone 5.

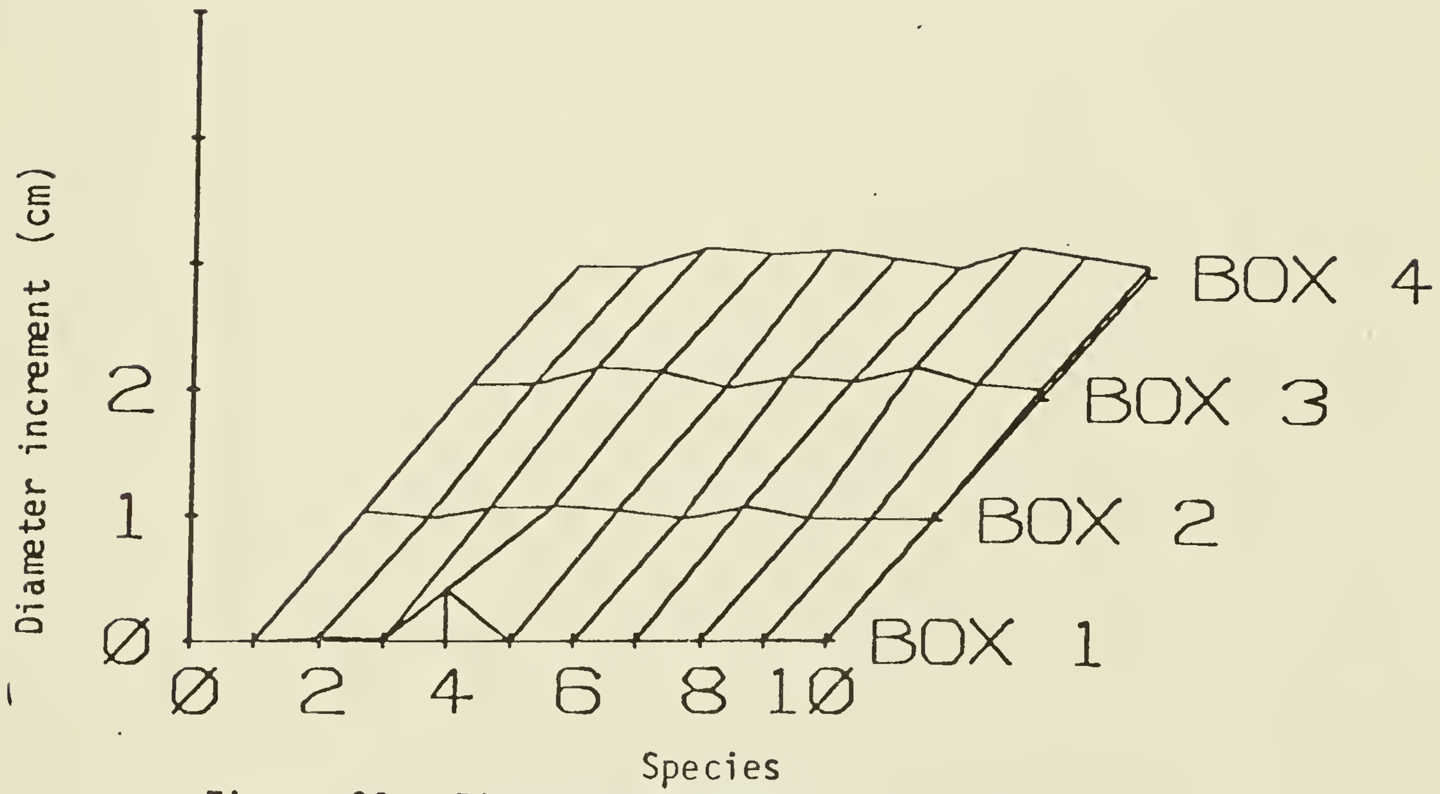

Figure 23. Diameter increment for zone 1.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

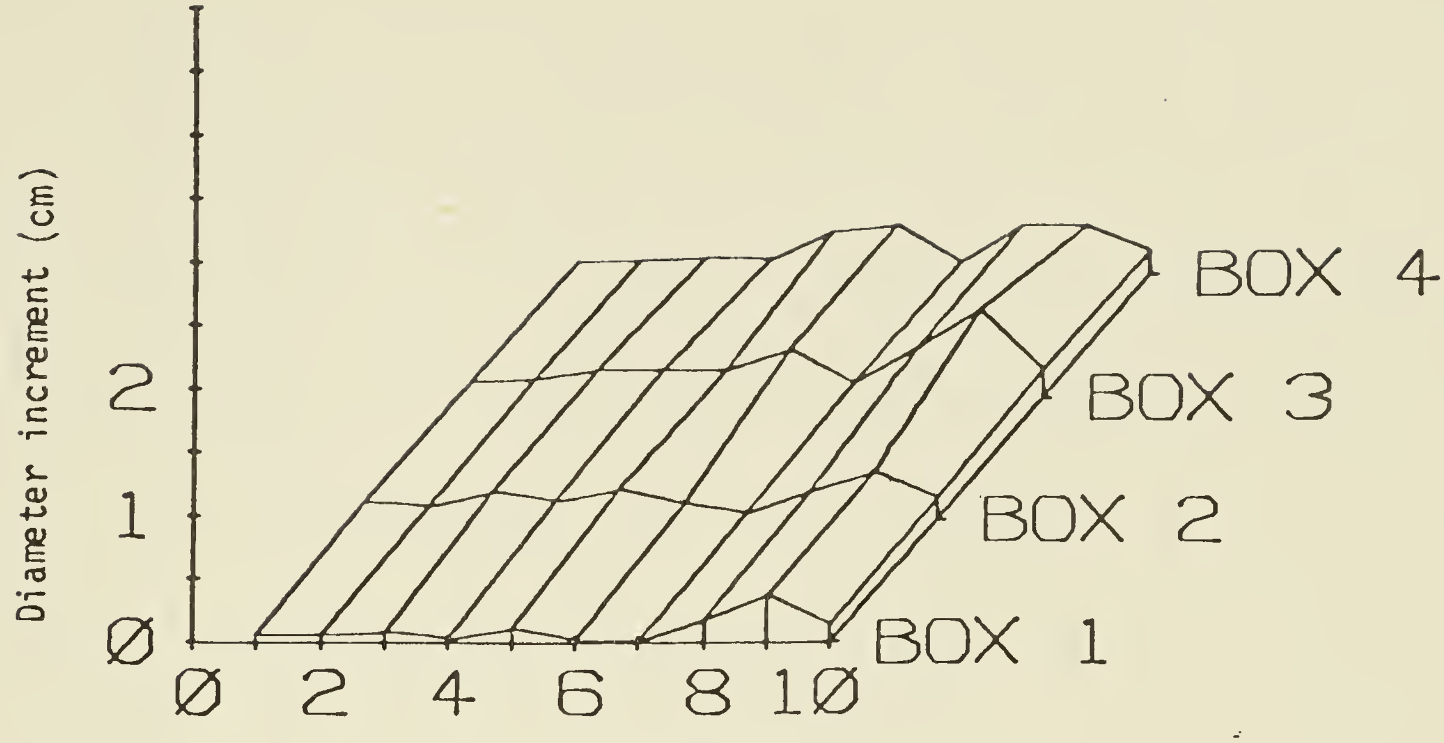

Figure 24. Diameter increment for zone 2.

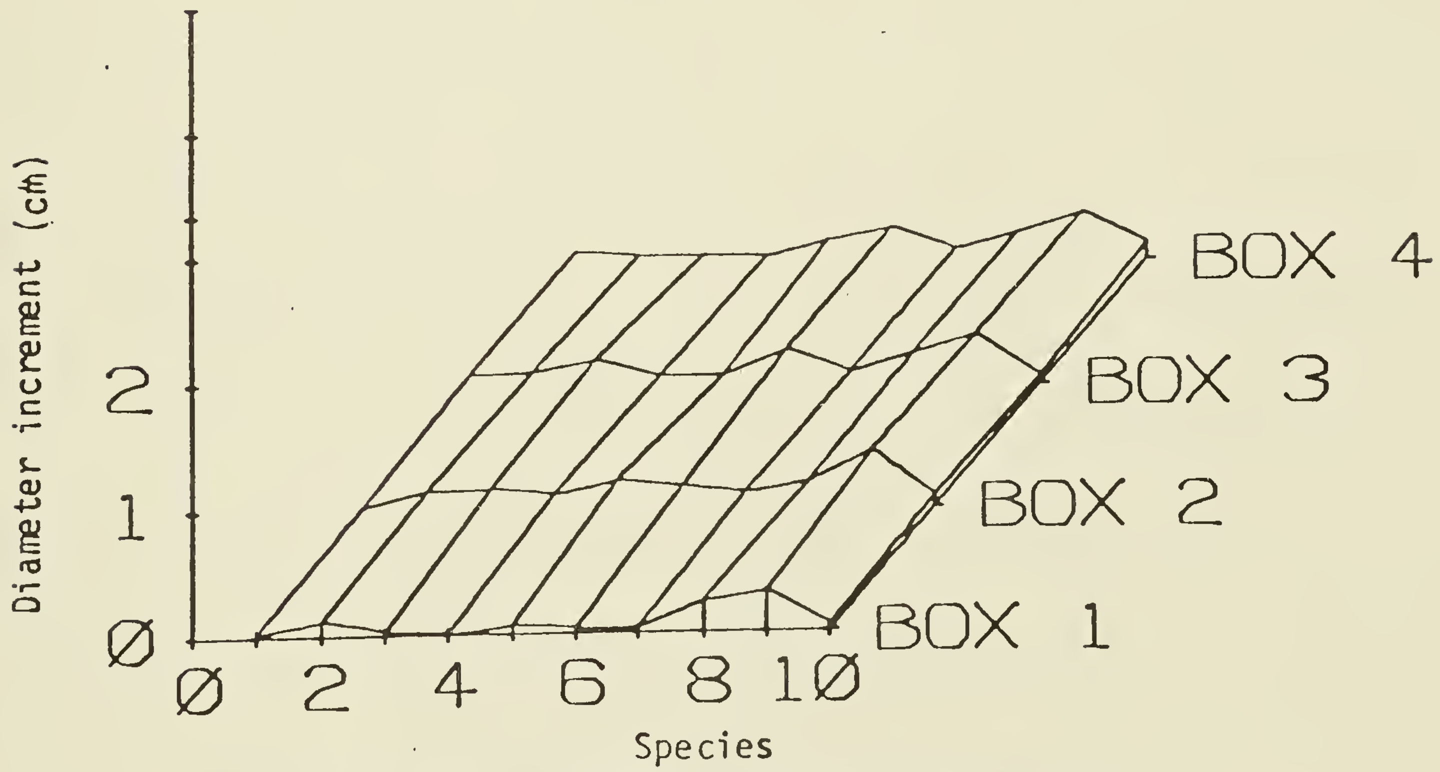

Figure 25. Diameter increment for zone 3.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

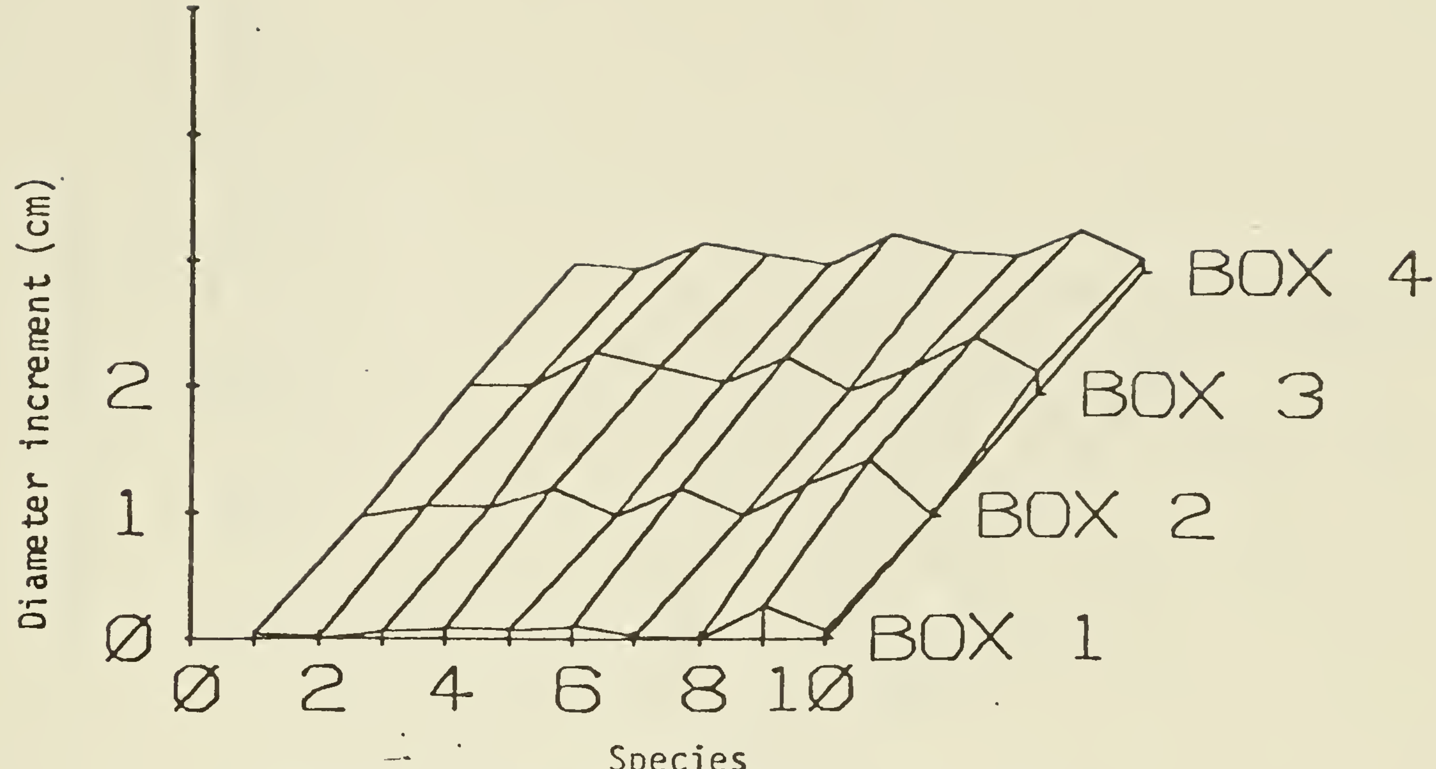

Figure 26. Diameter increment for zone 4.

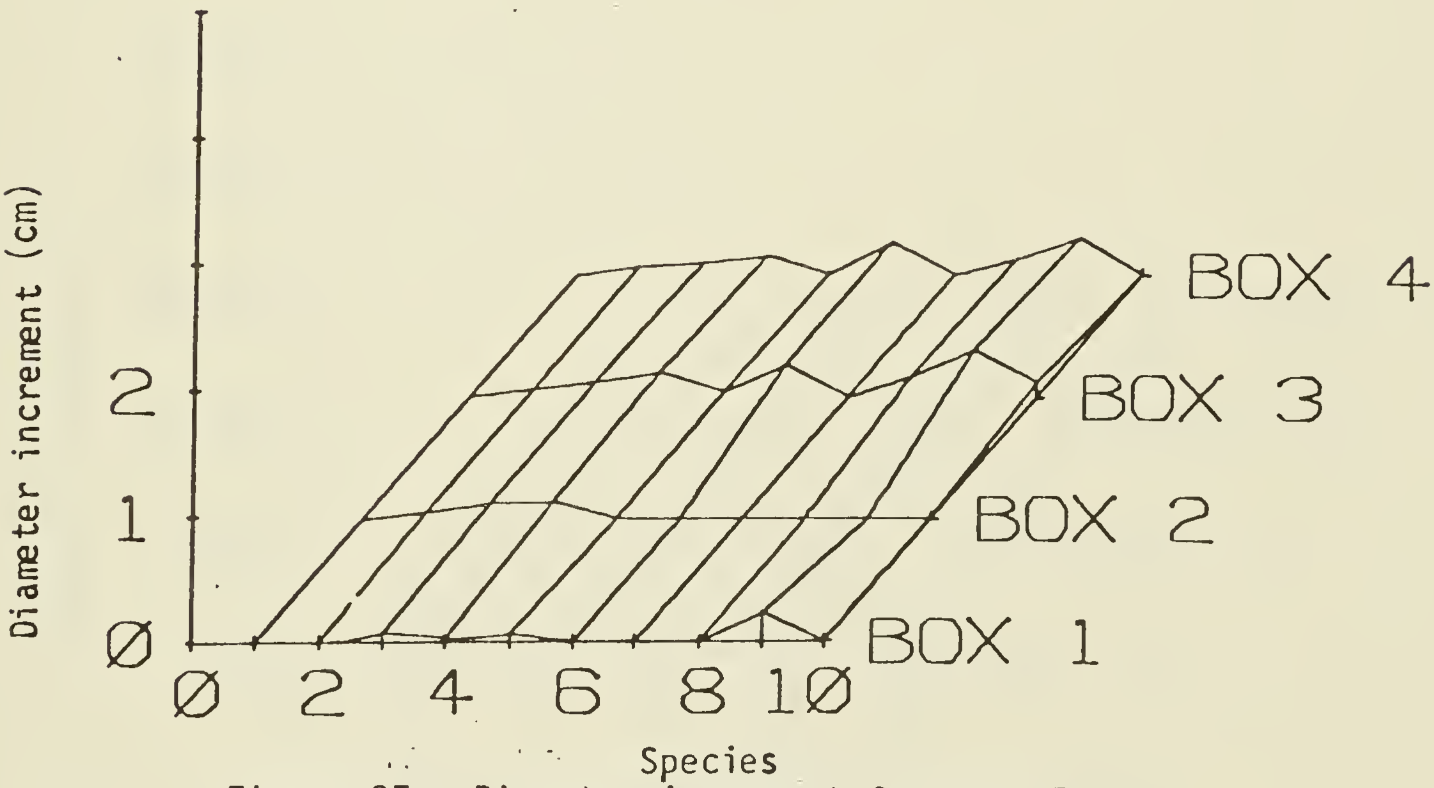

Figure 27. Diameter increment for zone 5.

<u>Code used for Species:</u>

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

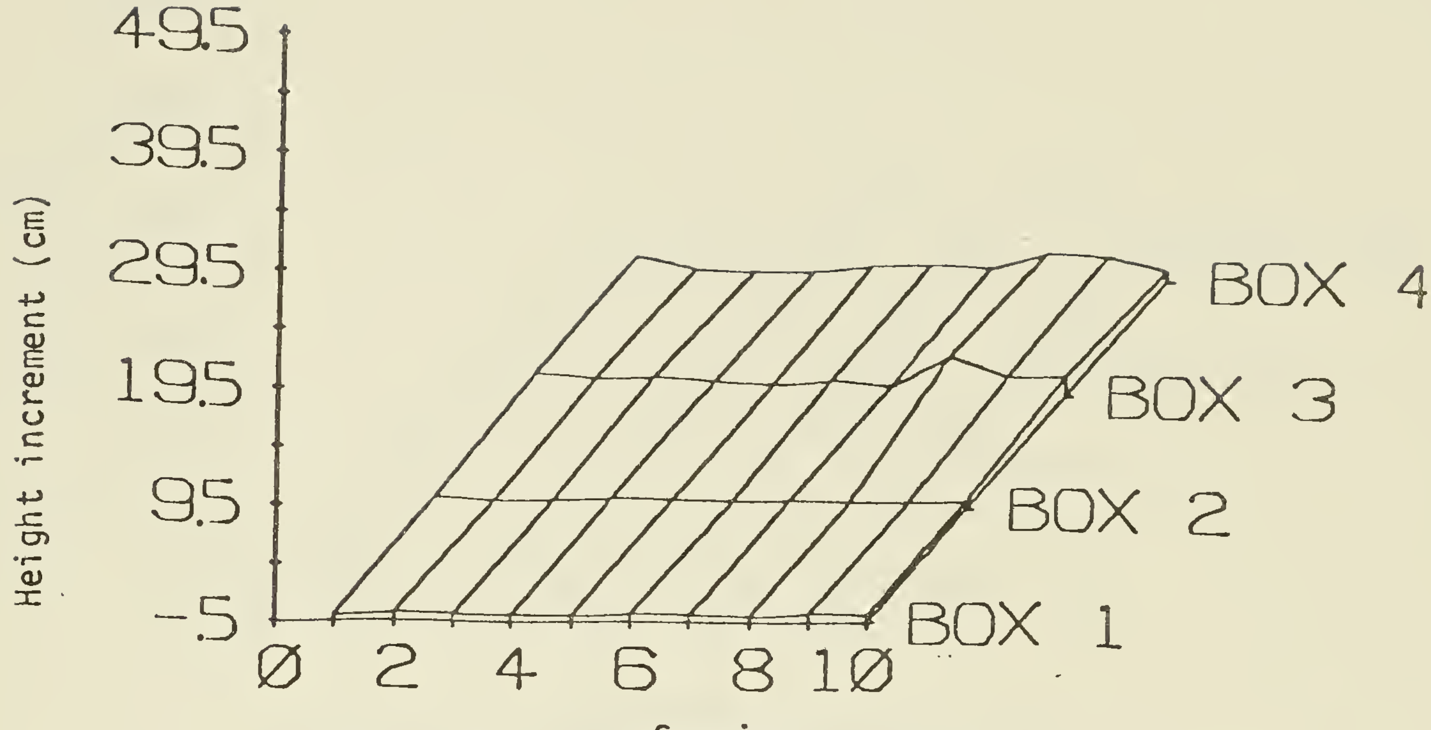

Figure 28. Height increment for zone 1.

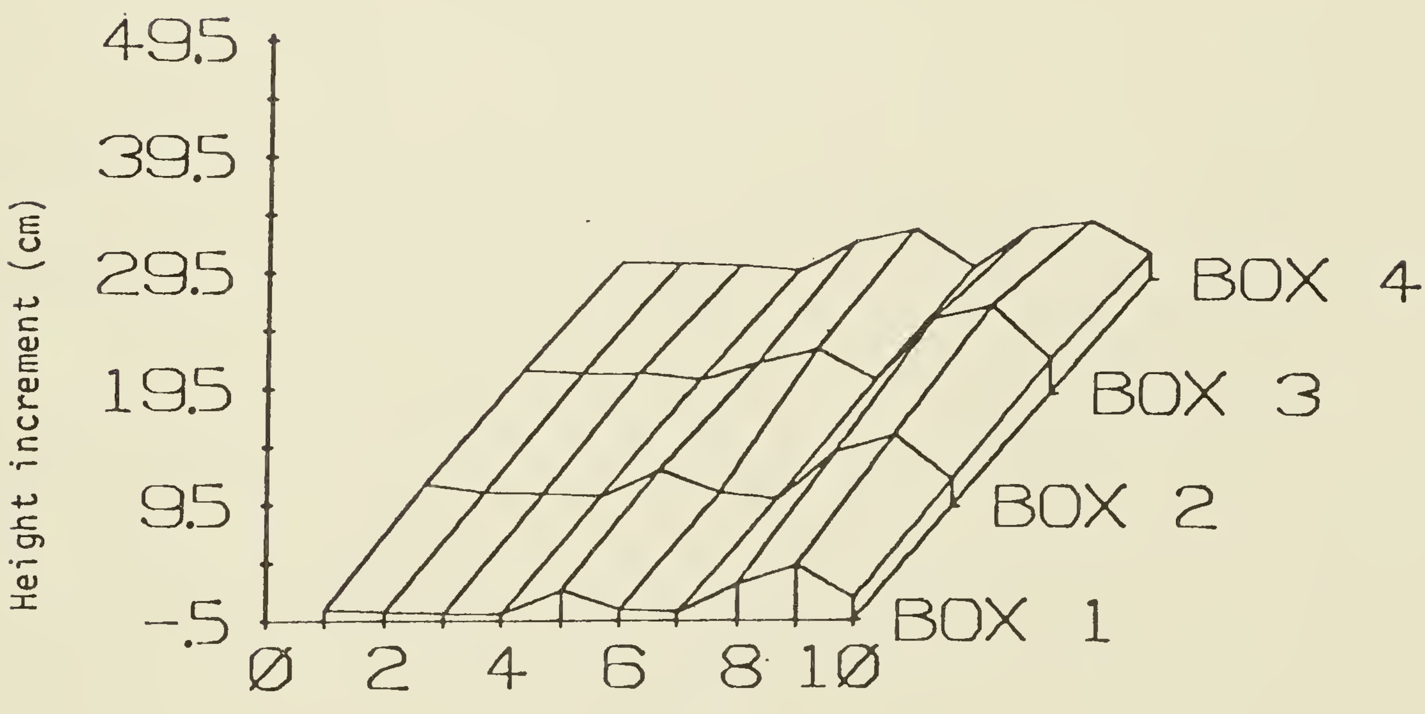

Figure 29. Height increment for zone 2.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

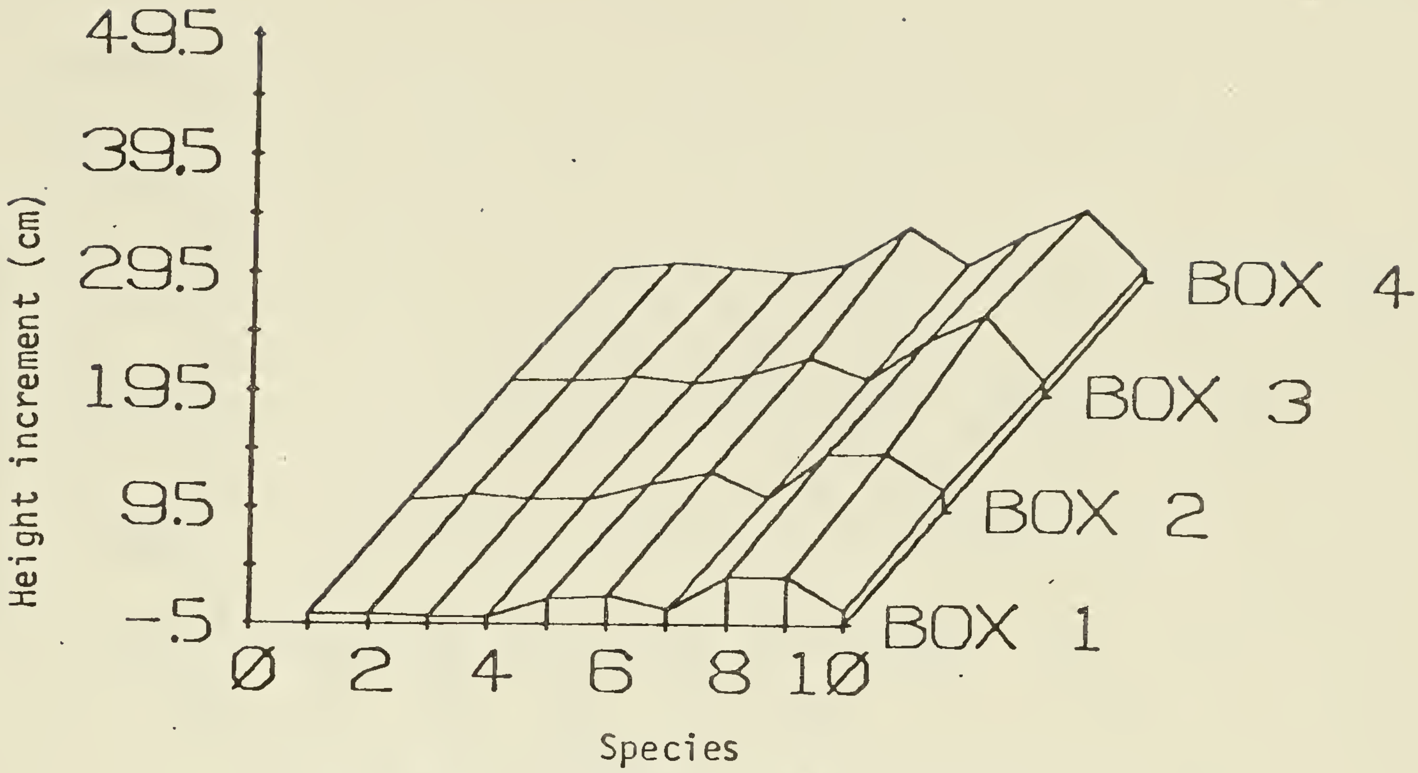

Figure 30. Height increment for zone 3.

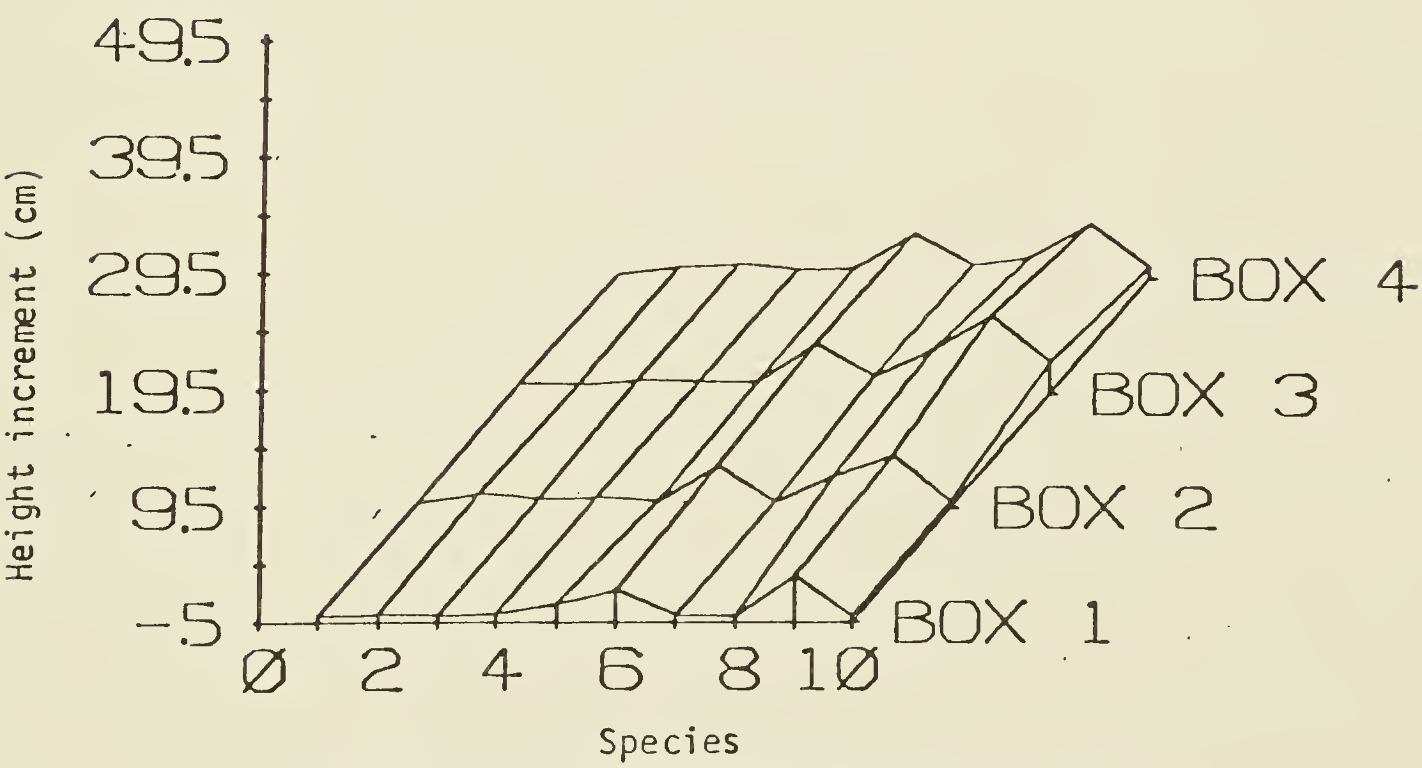

Figure 31. Height increment for zone 4.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

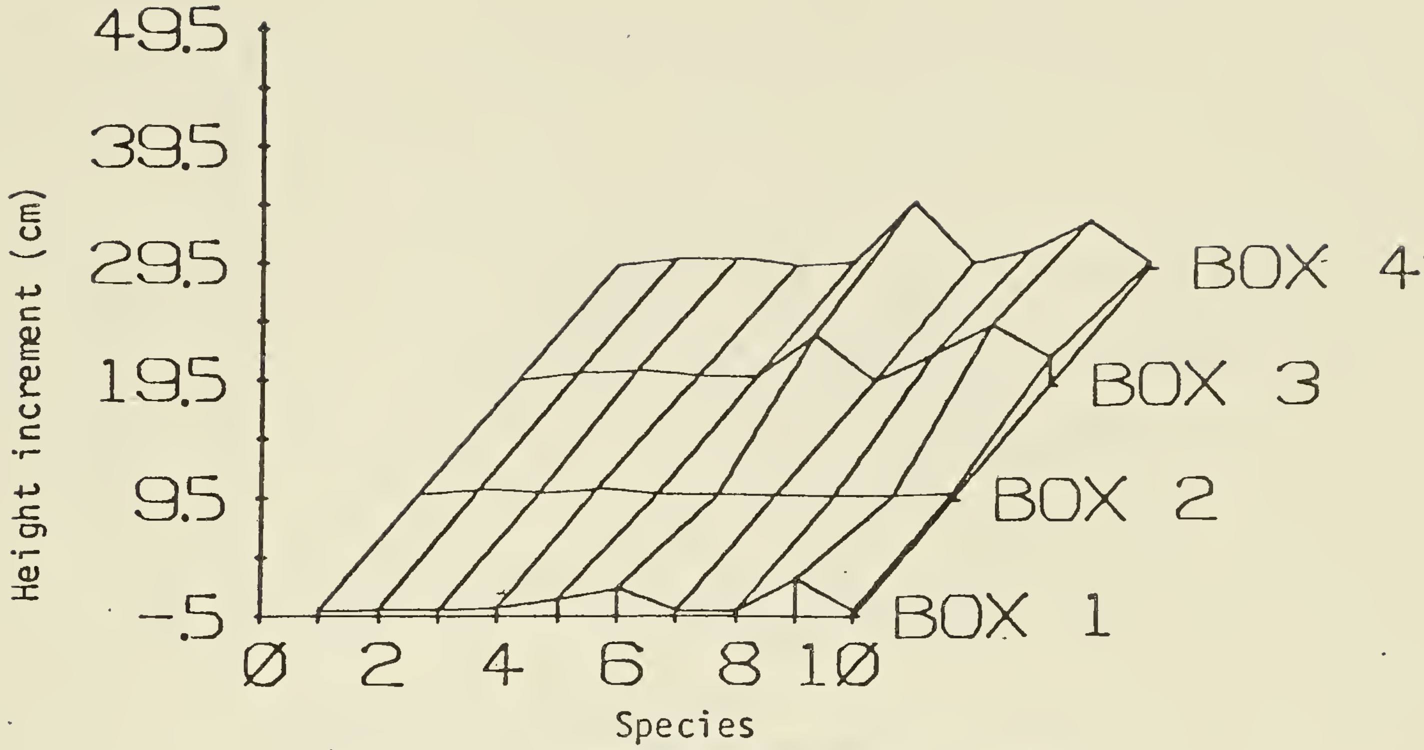

Figure 32. Height increment for zone 5.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

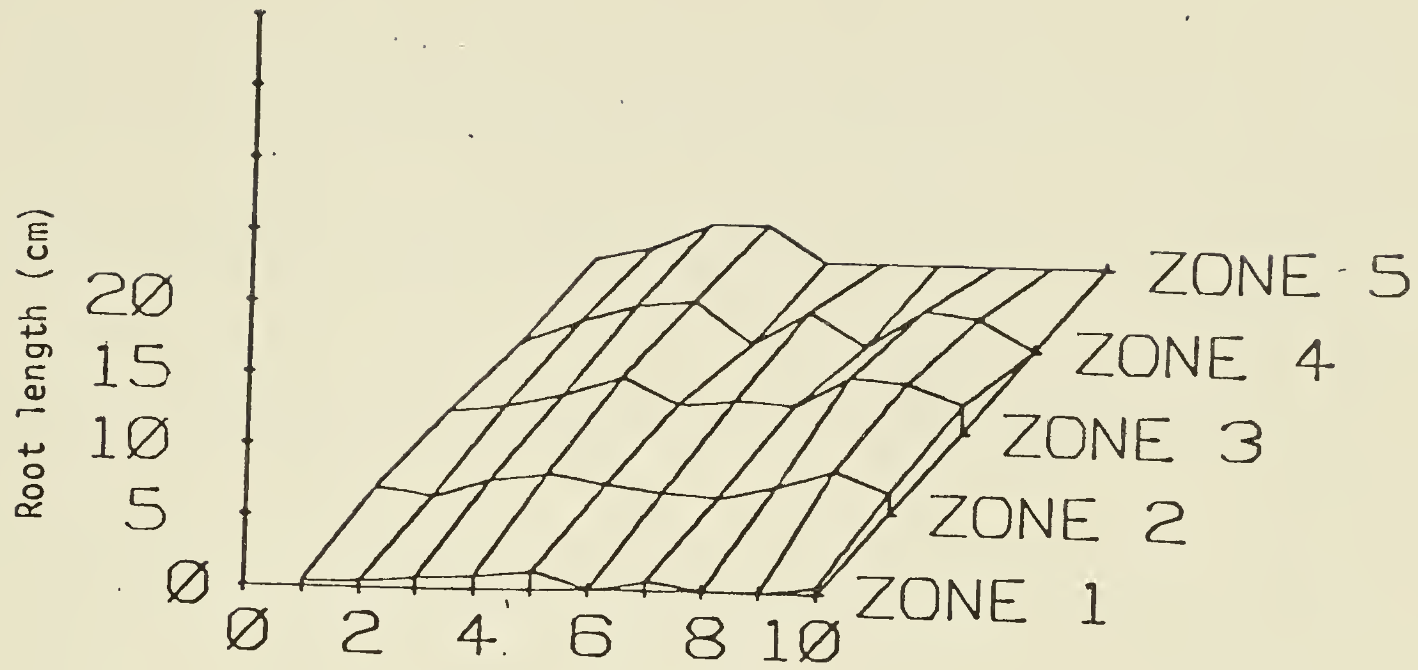

Figure 33. Box 2, Root length.

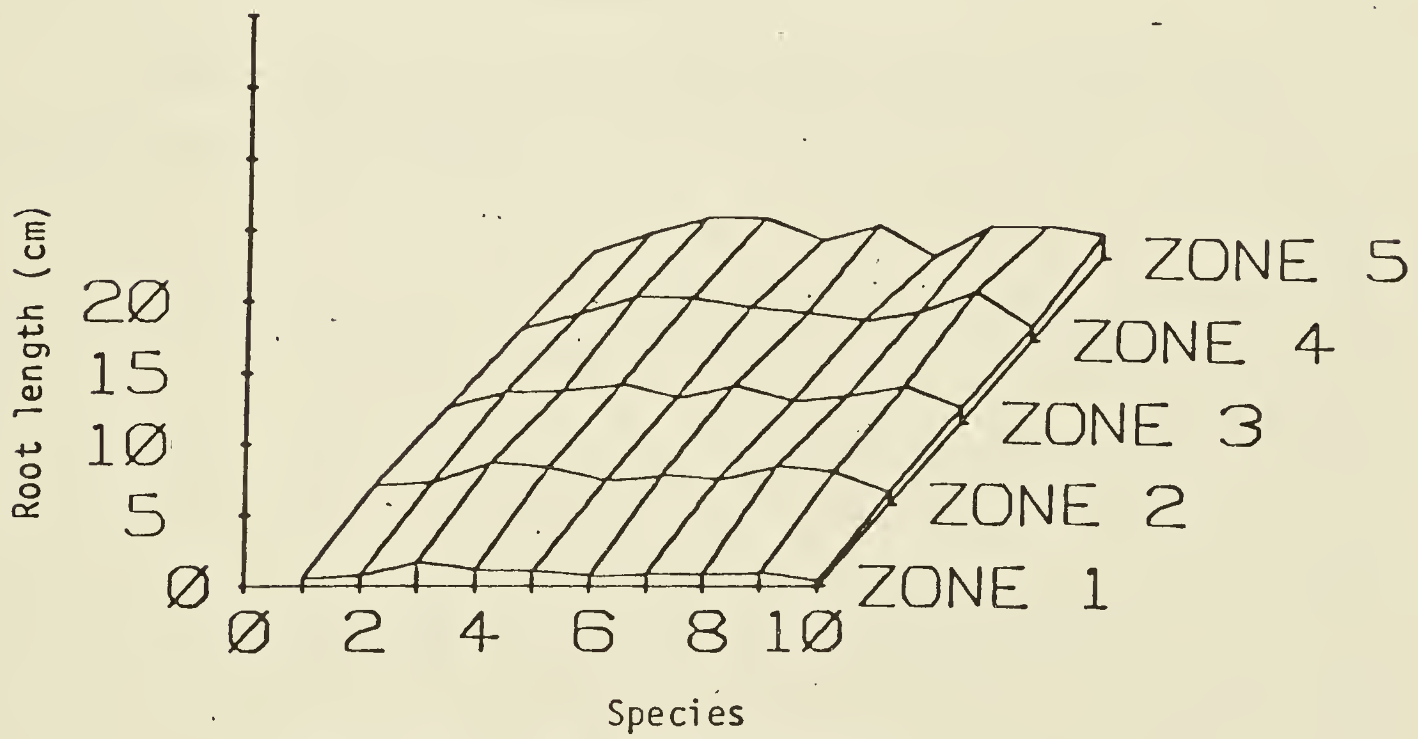

Figure 34. Box 3, Root length.

Code used for Species:

1. black spruce
2. white spruce
3. lodgepole pine
4. ponderosa pine
5. western redcedar
6. Douglas-fir
7. western hemlock
8. western larch
9. Siberian larch
10. tamarack

APPENDIX 5

Tables showing multiple comparisons between species per zone for various measurements.

TABLE 12. PERCENT SURVIVAL INTERACTION BETWEEN ZONES (S.E.M. 4.05%)

Treatments	Zones	ta	lw	ls	lp	pp	sb	sw	df	wr	wh
Vegetated sandy loam soil	1	77^{b}	8^{c}	45^{b}	85^{a}	89^{b}	95^{b}	50^{b}	55^{b}	50^{c}	19^{c}
	2	95^{a}	80^{a}	97^{a}	85^{a}	95^{ab}	100^{a}	100^{a}	100^{a}	100^{a}	85^{a}
	3	43^{c}	60^{b}	95^{a}	92^{a}	100^{a}	75^{c}	100^{a}	100^{a}	100^{a}	66^{b}
	4	15^{d}	11^{c}	65^{b}	92^{a}	100^{a}	40^{d}	95^{a}	98^{a}	80^{b}	30^{c}
	5	5^{d}	8^{c}	55^{b}	97^{a}	95^{ab}	11^{e}	65^{b}	80^{a}	30^{d}	0^{d}
Non-vegetated sandy loam soil	1	85^{b}	0^{c}	18^{c}	92^{b}	85^{a}	80^{b}	15^{c}	18^{c}	8^{cd}	25^{c}
	2	100^{a}	71^{a}	72^{a}	85^{b}	92^{a}	100^{a}	100^{ab}	100^{a}	100^{a}	95^{a}
	3	95^{b}	40^{b}	71^{a}	100^{a}	97^{a}	71^{b}	100^{a}	100^{a}	92^{b}	71^{b}
	4	5^{c}	3^{c}	45^{b}	97^{ab}	92^{a}	11^{c}	85^{b}	90^{b}	85^{c}	5^{d}
	5	0^{d}	0^{c}	18^{c}	92^{b}	92^{a}	0^{d}	75^{b}	68^{c}	19^{d}	0^{e}
Non-vegetated silty clay soil	1	95^{b}	56^{bc}	56^{bc}	72^{b}	71^{b}	100^{a}	45^{b}	60^{b}	65^{b}	32^{b}
	2	65^{a}	95^{a}	100^{a}	85^{ab}	95^{a}	100^{a}	100^{a}	100^{a}	100^{a}	55^{a}
	3	32^{c}	92^{a}	100^{a}	92^{ab}	100^{a}	92^{b}	100^{a}	100^{a}	100^{a}	66^{a}
	4	19^{c}	40^{cd}	70^{b}	92^{ab}	100^{a}	40^{c}	100^{a}	100^{a}	75^{b}	30^{b}
	5	5^{d}	30^{d}	60^{b}	97^{a}	95^{a}	40^{c}	100^{a}	95^{a}	30^{c}	0^{c}
Vegetated silty clay soil	1	75^{b}	28^{b}	27^{c}	82^{c}	66^{b}	95^{b}	28^{c}	23^{d}	32^{c}	39^{b}
	2	100^{a}	89^{a}	85^{a}	85^{bc}	92^{a}	100^{a}	85^{a}	100^{a}	100^{a}	71^{a}
	3	89^{b}	77^{d}	89^{a}	100^{a}	97^{a}	89^{b}	89^{a}	100^{a}	92^{b}	71^{a}
	4	8^{c}	23^{b}	50^{b}	97^{ab}	92^{a}	11^{c}	50^{b}	82^{b}	23^{c}	5^{c}
	5	0^{d}	8^{c}	23^{c}	92^{bc}	92^{a}	11^{c}	23^{c}	50^{c}	8^{d}	0^{d}

Code used for species: ta - tamarack lw - western larch ls - Siberian larch lp - lodgepole pine
pp - ponderosa pine sb - black spruce sw - white spruce df - Douglas-fir
wr - western redcedar wh - western hemlock S.E.M. - standard error of the mean

Code used for multiple comparisons; any letter duplicated in a group of numbers means the appropriate numbers are not significantly different from each other

TABLE 13. HEIGHT INTERACTION BETWEEN ZONES (S.E.M. 1.52)(CM).

Treatments	Zones	ta	lw	ls	lp	pp	sb	sw	df	wr	wh
Vegetated sandy loam soil	1	6^{b}	14^{bc}	6^{d}	2^{a}	2^{a}	5^{ab}	3^{a}	5^{d}	1^{d}	1^{b}
	2	19^{a}	44^{a}	57^{a}	6^{a}	3^{a}	8^{a}	7^{a}	18^{c}	21^{a}	4^{ab}
	3	7^{b}	39^{a}	50^{b}	3^{a}	2^{a}	5^{ab}	4^{a}	23^{b}	14^{b}	8^{a}
	4	11^{b}	16^{b}	48^{b}	6^{a}	3^{a}	2^{c}	2^{a}	30^{a}	8^{c}	5^{ab}
	5	9^{b}	11^{c}	36^{c}	4^{a}	3^{a}	$.1^{c}$	3^{a}	29^{a}	7^{c}	0^{b}
Non-vegetated sandy loam soil	1	1^{c}	0^{d}	1^{d}	4^{a}	1^{a}	1^{b}	1^{a}	1^{c}	$-.05^{d}$	2^{a}
	2	16^{a}	35^{b}	50^{a}	9^{a}	2^{a}	8^{a}	4^{a}	5^{b}	23^{b}	2^{a}
	3	10^{b}	40^{a}	41^{b}	6^{a}	2^{a}	3^{b}	5^{a}	23^{a}	16^{a}	6^{a}
	4	0^{c}	12^{c}	39^{b}	8^{a}	3^{a}	0^{b}	5^{a}	27^{a}	5^{c}	0^{a}
	5	0^{c}	0^{d}	13^{c}	8^{a}	4^{a}	0^{b}	2^{a}	9^{b}	5^{c}	0^{a}
Non-vegetated silty clay soil	1	8^{c}	24^{c}	13^{d}	4^{a}	4^{a}	11^{a}	3^{b}	8^{c}	5^{c}	3^{bc}
	2	21^{a}	50^{a}	58^{a}	6^{a}	4^{a}	12^{a}	10^{a}	36^{b}	25^{a}	6^{ab}
	3	6^{c}	38^{b}	60^{a}	5^{a}	3^{a}	6^{b}	7^{ab}	35^{b}	12^{b}	9^{a}
	4	14^{b}	24^{c}	52^{b}	4^{a}	4^{a}	2^{bc}	5^{ab}	36^{b}	5^{c}	9^{a}
	5	9^{c}	17^{d}	41^{c}	4^{a}	2^{a}	0^{c}	6^{ab}	47^{a}	4^{c}	0^{c}
Vegetated silty clay soil	1	3^{c}	10^{c}	8^{d}	2^{a}	3^{a}	7^{b}	1^{b}	4^{d}	4^{c}	4^{ab}
	2	18^{a}	41^{a}	51^{a}	6^{a}	3^{a}	12^{a}	7^{a}	23^{c}	27^{a}	3^{ab}
	3	9^{b}	39^{a}	51^{a}	3^{a}	3^{a}	4^{bc}	7^{a}	34^{a}	14^{b}	7^{a}
	4	3^{c}	19^{b}	42^{b}	6^{a}	4^{a}	0^{c}	7^{a}	33^{a}	3^{c}	4^{ab}
	5	0^{c}	6^{c}	18^{c}	4^{a}	3^{a}	0^{c}	5^{a}	27^{b}	2^{c}	0^{b}

Code used for species: ta - tamarack lw - western larch ls - Siberian larch lp - lodgepole pine
pp - ponderosa pine sb - black spruce sw - white spruce df - Douglas fir
wr - western redcedar wh - western hemlock S.E.M. - standard error of the mean

* see table 12 for explanation of code.

TABLE 14. DIAMETER INTERACTION BETWEEN ZONES (S.E.M. .02)(CM)

Treatments	Zones	ta	lw	ls	lp	pp	sb	sw	df	wr	wh
Vegetated sandy loam soil	1	$.04^{c}$	$.11^{b}$	$.06^{a}$	$.13^{b}$	$.3^{a}$	$.05^{ab}$	$.07^{ab}$	$.09^{c}$	$.04^{b}$	$.07^{ab}$
	2	$.18^{a}$	$.28^{a}$	$.53^{a}$	$.15^{ab}$	$.12^{b}$	$.1^{a}$	$.11^{a}$	$.21^{a}$	$.17^{a}$	$.06^{ab}$
	3	$.06^{bc}$	$.13^{a}$	$.36^{b}$	$.13^{b}$	$.05^{c}$	$.08^{a}$	$.13^{a}$	$.17^{ab}$	$.09^{b}$	$.08^{a}$
	4	$.13^{b}$	$.08^{b}$	$.35^{b}$	$.2^{a}$	$.15^{b}$	$.06^{ab}$	$.04^{b}$	$.2^{a}$	$.08^{b}$	$.02^{ab}$
	5	$.06^{bc}$	$.08^{n}$	$.3^{n}$	$.1^{n}$	$.12^{n}$	$.01^{n}$	$.04^{n}$	$.13^{nc}$	$.05^{b}$	0^{b}
Non-vegetated sandy loam soil	1	0^{c}	0^{c}	$.1^{c}$	$.05^{b}$	$.25^{a}$	$.02^{b}$	$.02^{b}$	$.01^{c}$	$.03^{b}$	$.05^{ab}$
	2	$.15^{a}$	$.2^{a}$	$.4^{a}$	$.15^{a}$	$.09^{c}$	$.1^{a}$	$.08^{b}$	$.07^{b}$	$.18^{a}$	$.03^{ab}$
	3	$.07^{b}$	$.25^{a}$	$.4^{a}$	$.11^{ab}$	$.07^{c}$	$.04^{b}$	$.15^{a}$	$.11^{ab}$	$.16^{a}$	$.09^{a}$
	4	$.03^{bc}$	$.13^{b}$	$.4^{a}$	$.07^{b}$	$.15^{b}$	$.02^{b}$	$.05^{b}$	$.16^{a}$	$.04^{b}$	$.01^{b}$
	5	0^{c}	0^{c}	$.01^{b}$	$.1^{ab}$	$.25^{c}$	0^{b}	$.13^{b}$	0^{c}	$.03^{b}$	0^{b}
Non-vegetated silty clay soil	1	$.07^{c}$	$.24^{b}$	$.13^{c}$	$.23^{a}$	$.19^{a}$	$.09^{a}$	$.09^{ab}$	$.39^{c}$	$.15^{b}$	$.1^{a}$
	2	$.2^{a}$	$.39^{a}$	$.54^{a}$	$.18^{b}$	$.16^{a}$	$.12^{a}$	$.13^{a}$	$.15^{a}$	$.28^{a}$	$.1^{a}$
	3	$.1^{bc}$	$.25^{b}$	$.4^{b}$	$.15^{b}$	$.08^{b}$	$.12^{a}$	$.11^{ab}$	$.3^{b}$	$.15^{b}$	$.12^{a}$
	4	$.14^{b}$	$.17^{c}$	$.4^{b}$	$.28^{a}$	$.17^{a}$	$.07^{a}$	$.04^{b}$	$.3^{b}$	$.07^{c}$	$.01^{a}$
	5	$.06^{c}$	$.15^{c}$	$.34^{b}$	$.12^{b}$	$.18^{a}$	$.01^{b}$	$.07^{ab}$	$.26^{b}$	$.02^{c}$	0^{b}
Vegetated silty clay soil	1	$.04^{c}$	$.07^{d}$	$.08^{c}$	$.16^{a}$	$.14^{ab}$	$.06^{bc}$	$.03^{c}$	$.07^{c}$	$.14^{c}$	$.08^{a}$
	2	$.17^{a}$	$.31^{a}$	$.38^{a}$	$.18^{a}$	$.13^{ab}$	$.12^{a}$	$.11^{ab}$	$.26^{a}$	$.29^{a}$	$.07^{a}$
	3	$.11^{b}$	$.24^{b}$	$.42^{a}$	$.13^{a}$	$.1^{b}$	$.08^{ab}$	$.12^{a}$	$.23^{a}$	$.22^{b}$	$.12^{a}$
	4	$.05^{c}$	$.19^{c}$	$.4^{a}$	$.15^{a}$	$.18^{a}$	$.03^{bc}$	$.05^{bc}$	$.26^{a}$	$.03^{d}$	$.08^{a}$
	5	0^{c}	$.12^{d}$	$.15^{b}$	$.12^{a}$	$.15^{ab}$	0^{c}	$.07^{abc}$	$.13^{b}$	0^{d}	0^{b}

Code used for species: ta - tamarack lw - western larch ls - Siberian larch lp - lodgepole pine
pp - ponderosa pine sb - black spruce sw - white spruce df - Douglas-fir
wr - western redcedar wh - western hemlock S.E.M. - standard error of the mean

* see table 12 for explanation of code.

TABLE 15. ROOT LENGTH INTERACTION BETWEEN ZONES (S.E.M. 1.78)(CM).

Treatments	Zones	ta	lw	ls	lp	pp	sb	sw	df	wr	wh
Non-vegetated conditions of both the sandy loam and silty clay soils	1	4.6^{c}	4.5^{c}	4.8^{c}	12.5^{a}	10.7^{b}	4.7^{bc}	6.7^{b}	3.6^{c}	3.6^{c}	7.7^{bc}
	2	11.6^{ab}	27.3^{a}	25.7^{a}	23.9^{a}	23.9^{a}	12.3^{a}	11.3^{ab}	15^{b}	15^{b}	12.5^{ab}
	3	14.7^{a}	21.6^{a}	28.8^{a}	21.5^{a}	29.4^{a}	9.6^{ab}	17^{a}	21.6^{a}	21.6^{a}	14.2^{a}
	4	4.5^{c}	23^{a}	27.7^{a}	27.6^{a}	28.4^{a}	3.1^{c}	16^{a}	20.4^{a}	20.4^{a}	6.3^{c}
	5	8^{bc}	11^{b}	28.8^{b}	26.1^{b}	28^{a}	1.4^{c}	12^{ab}	11.3^{b}	11.3^{b}	0^{d}

Code used for species:

ta - tamarack
lw - western larch
ls - Siberian larch
lp - lodgepole pine
pp - ponderosa pine
sb - black spruce
sw - white spruce
df - Douglas-fir
wr - western redcedar
wh - western hemlock
S.E.M. - standard error of the mean

* see table 12 for explanation of code.

APPENDIX 6

Water table and averaged wetted perimeter depths.

TABLE 16. WATER TABLE AND AVERAGED WETTED PERIMETER DEPTHS:

	sandy loam	silty clay
Average depth to water:		
upper set of piezometers:	85 cm	76 cm
middle set of piezometers:	55 cm	50 cm
lower set of piezometers:	10 cm	10 cm
Average wetted perimeter:		
upper set of tensiometers:	15 cm	15 cm
lower set of tensiometers:	2 cm	2 cm

APPENDIX 7

Percent survival per flooded day per species tested.

TABLE 17. REACTION OF SEVERAL SPECIES OF ACTIVELY GROWING SEEDLINGS TO FLOODING OF VARIOUS DURATIONS.

	Day flooded									
Species	1	2	3	4	5	6	7	8	9	10
	Percent survival									
lodgepole pine	100	100	100	100	100	100	100	100	40	40
tamarack	100	100	75	60	60	0	0	0	0	0
white spruce	100	100	100	100	100	100	100	100	100	70
black spruce	100	100	100	75	75	50	0	0	0	0
Siberian larch	100	100	75	0	0	0	0	0	0	0
Douglas-fir	100	100	100	65	65	40	15	0	0	0